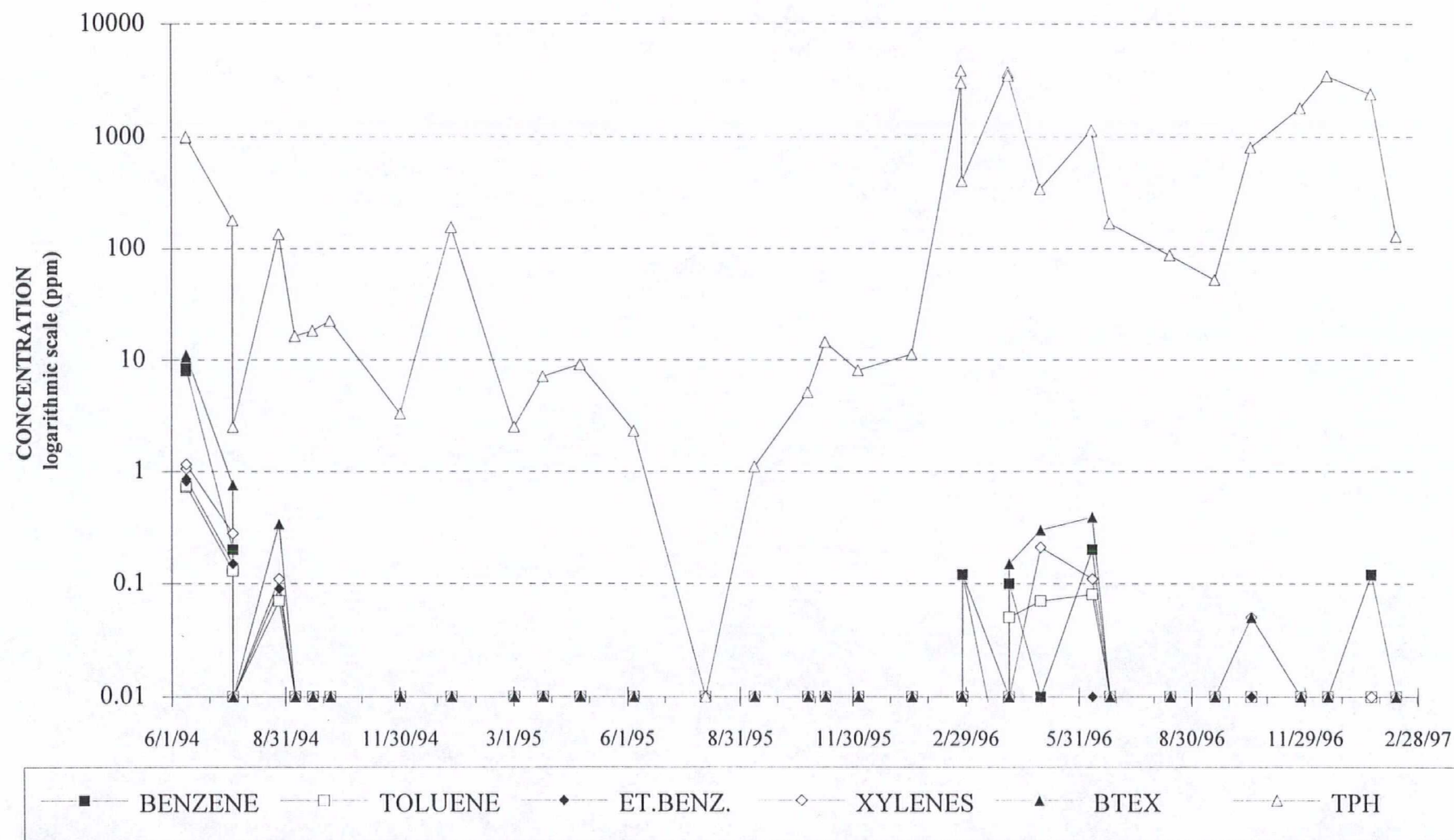


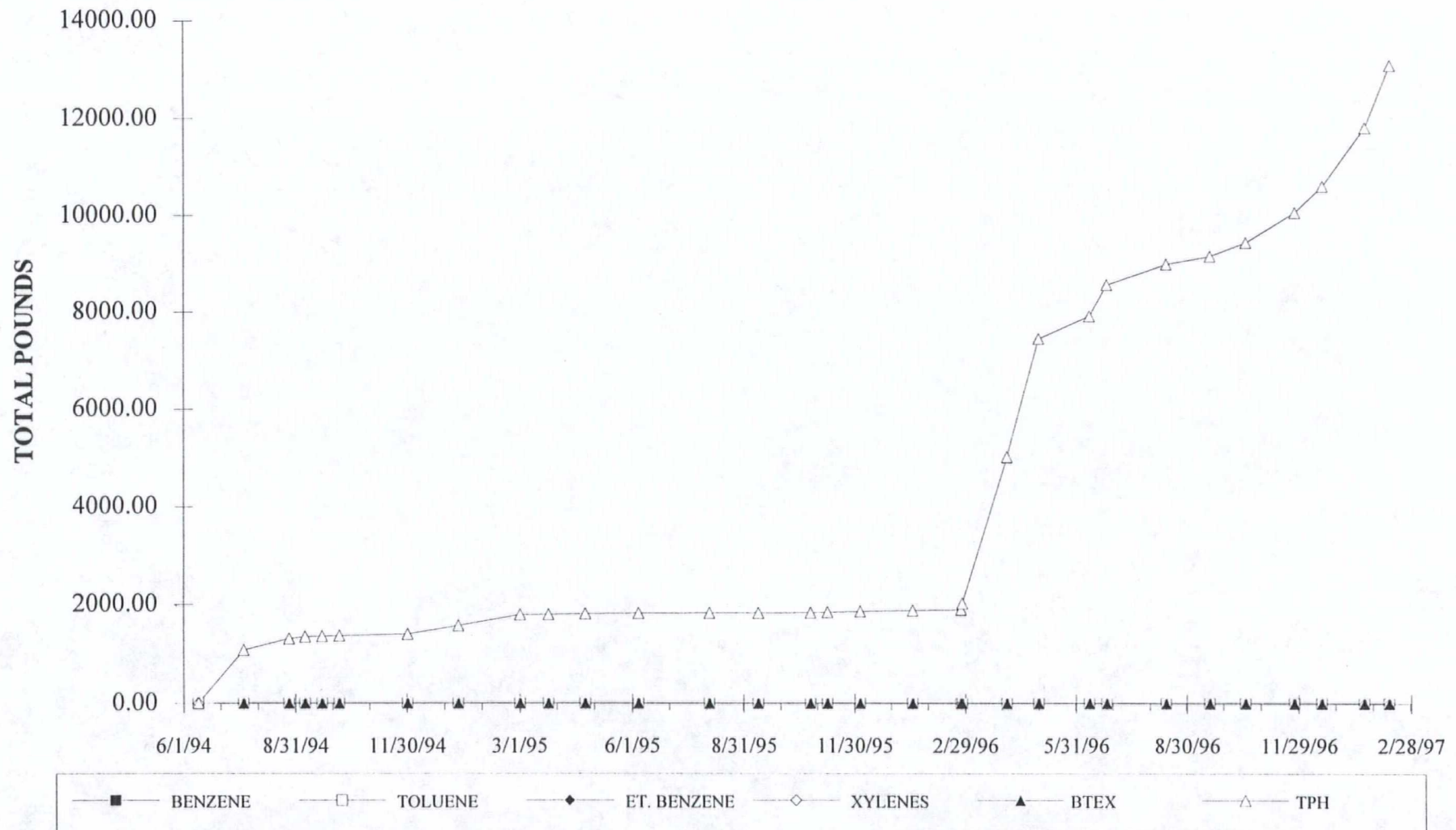
Figure 2
OFF - GAS CONCENTRATION OF VOCs
SOIL VAPOR EXTRACTION SYSTEM - COMPOSITE SAMPLE
G. E. CELL 46 : CINCINNATI, OHIO



TPH detection limit = 1 ppm

BTEX detection limit = .05 ppm

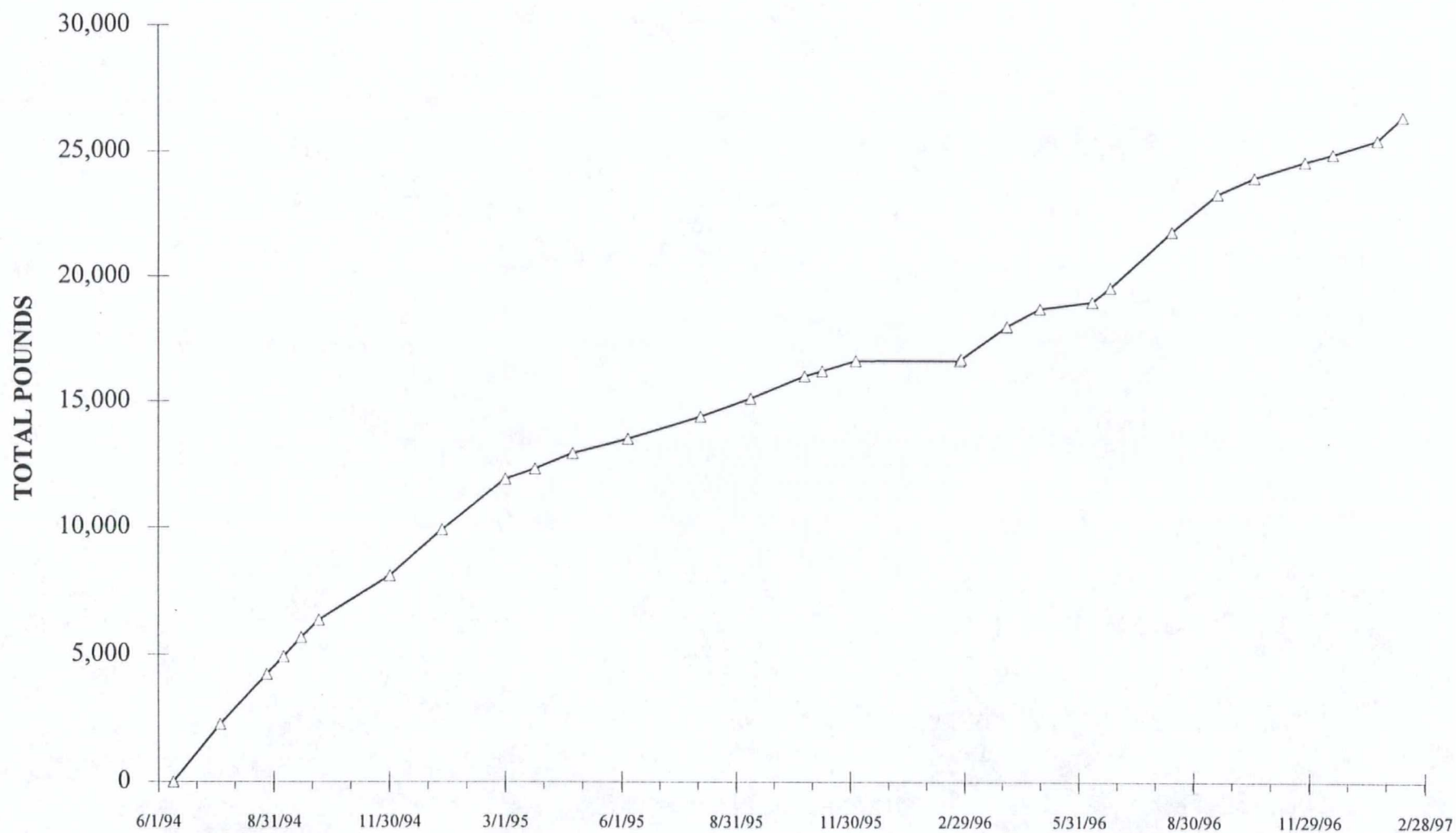
Figure 3
CUMULATIVE YIELD OF VOCs
SOIL VAPOR EXTRACTION SYSTEM - COMPOSITE SAMPLE
G.E. CELL 46: CINCINNATI, OHIO



Note: 6/23/95 sample was calculated from well samples.

3/11/97

Figure 4
CUMULATIVE YIELD OF HYDROCARBON BIODEGRADATION
SOIL VAPOR EXTRACTION SYSTEM - COMPOSITE SAMPLE
GE CELL 46: CINCINNATI, OHIO



Note: 6/23/95 sample was calculated from well samples.

3/13/97

TABLES

Table 1: OFF GAS CONCENTRATIONS

CLIENT: G. E. CELL 46

CLIENT CODE: 2002

ANALYST: T. LONIEWSKI

PROJECT MANGER: M. HOLLAND

FIELD DATA					LAB DATA (ppm)					
SAMPLE DATE	SAMPLE #	WELL #	FLOW (CFM)	CO2 (PPM)	BENZENE	TOLUENE	ET.BENZ.	XYLENES	BTEX	TPH
9/18/96	11	11	19	1,650						4.6
9/18/96	14	14	19	4,150						1
9/18/96	17	17	19	1,150						1.1
9/18/96	18	18	12	4,950						1
9/18/96	31	31	19	2,000						1
9/18/96	33	33	19	600						1
9/18/96	35	35	19	3,700						1.2
9/18/96	57	57	4	10,000						1770
9/18/96	60	60	19	10,000						607
9/18/96	9	9	19	5,500						<1.0
9/18/96	COMP	COMP	168	4,950						52.7
10/17/96	11	11	21	6600				0.22	0.22	13.80
10/17/96	14	14	20	10,000		0.06		0.16	0.22	5.50
10/17/96	17	17	18	800		0.09		0.36	0.45	3.00
10/17/96	18	18	20	10,000				0.16	0.16	39.70
10/17/96	31	31	18	10,000		0.21		0.29	0.50	4.50
10/17/96	33	33	21	1,800				0.15	0.15	2.50
10/17/96	35	35	21	10,000				0.12	0.12	4.80
10/17/96	57	57	4	10,000	0.08	0.11		0.05	0.24	2680.00
10/17/96	60	60	21	10,000				0.06	0.06	2780.00
10/17/96	9	9	21	4,000				0.15	0.15	2.20
10/17/96	COMP	COMP	185	10,000				0.05	0.05	807.00
11/26/96	9	9	21	5,450						<1.0
11/26/96	11	11	21	8,900						5.20
11/26/96	14	14	23	10,000						7.70
11/26/96	17	17	25	2,700						2.10
11/26/96	18	18	19	10,000						42.70
11/26/96	31	31	23	10,000						4.50
11/26/96	33	33	21	3,250						2.50
11/26/96	35	35	19	10,000						16.20
11/26/96	57	57	4	10,000	2.27	0.22			2.49	7970.00
11/26/96	60	60	14	10,000	0.07				0.07	4150.00
11/26/96	COMP	COMP	190	10,000						1820.00

* Blank cells represent BQL results.

NA = Not analyzed

NS = Not Sampled

3/13/97

Table 1: OFF GAS CONCENTRATIONS

CLIENT: G. E. CELL 46

CLIENT CODE: 2002

ANALYST: T. LONIEWSKI

PROJECT MANGER: M. HOLLAND

FIELD DATA					LAB DATA (ppm)					
SAMPLE DATE	SAMPLE #	WELL #	FLOW (CFM)	CO2 (PPM)	BENZENE	TOLUENE	ET.BENZ.	XYLENES	BTEX	TPH
12/18/96	9	9	16	5,000						<1.0
12/18/96	11	11	16	5,600						5.50
12/18/96	14	14	16	10,000						3.40
12/18/96	17	17	16	2,000						<1.0
12/18/96	18	18	11	10,000						34.30
12/18/96	31	31	14	10,000						4.10
12/18/96	33	33	15	2,000						<1.0
12/18/96	35	35	14	10,000						1.50
12/18/96	57	57	3	10,000	4.74	0.53	0.05	0.20	5.52	5380.00
12/18/96	60	60	9	10,000	0.09				0.09	4510.00
12/18/96	COMP	COMP	130	10,000						3490.00
1/22/97	9	9	18	5,000						5.10
1/22/97	11	11	18	7,550						18.90
1/22/97	14	14	18	6,700						25.10
1/22/97	17	17	18	2,200						4.20
1/22/97	18	18	18	10,000						1780.00
1/22/97	31	31	18	4,750						150.00
1/22/97	33	33	18	1,600						1.90
1/22/97	35	35	18	8,000						7.90
1/22/97	57	57	5	10,000	9.31	0.47	0.08	0.44	10.30	7430.00
1/22/97	60	60	18	10,000	0.41	0.05			0.46	4510.00
1/22/97	COMP	COMP	167	10,000	0.12				0.12	2410.00
2/11/97	9	9	18	2,800						20.30
2/11/97	11	11	18	2,150						7.70
2/11/97	14	14	18	1,500						24.90
2/11/97	17	17	18	400						5.70
2/11/97	18	18	15	2,350						1.30
2/11/97	31	31	18	1,600						1.40
2/11/97	33	33	18	650						6.30
2/11/97	35	35	18	4,150						2.90
2/11/97	57	57	4	10,000	2.74	0.75		0.22	3.71	4710.00
2/11/97	60	60	18	10,000						598.00
2/11/97	COMP	COMP	163	3,900						129.00

* Blank cells represent BQL results.

NA = Not analyzed

NS = Not Sampled

3/13/97

Table 2: REMOVAL RATES OF CONTAMINANTS

CLIENT: G. E. CELL 46

CLIENT CODE: 2002

ANALYST: T. LONIEWSKI

PROJECT MANGER: M. HOLLAND

FIELD DATA		POUNDS OF CONTAMINANTS PER DAY						
SAMPLE DATE	WELL #	Hydrocarbon Biodegradation	BENZENE	TOLUENE	ET.BENZ.	XYLENES	BTEX	TPH
9/18/96	11	1.341						0.033
9/18/96	14	3.824						0.007
9/18/96	17	0.844						0.008
9/18/96	18	2.917						0.004
9/18/96	31	1.688						0.007
9/18/96	33	0.298						0.007
9/18/96	35	3.377						0.009
9/18/96	57	2.028						2.653
9/18/96	60	9.634						4.321
9/18/96	9	5.165						
9/18/96	COMP	40.837						3.317
10/17/96	11	6.916				0.002	0.002	0.109
10/17/96	14	10.141		0.000		0.001	0.002	0.041
10/17/96	17	0.470		0.001		0.003	0.003	0.020
10/17/96	18	10.141				0.001	0.001	0.298
10/17/96	31	9.127		0.001		0.002	0.003	0.030
10/17/96	33	1.647				0.001	0.001	0.020
10/17/96	35	10.648				0.001	0.001	0.038
10/17/96	57	2.028	0.000	0.000		0.000	0.000	4.017
10/17/96	60	10.648				0.001	0.001	21.875
10/17/96	9	4.062				0.001	0.001	0.017
10/17/96	COMP	93.806				0.004	0.004	55.941
11/26/96	9	5.653						
11/26/96	11	9.441						0.041
11/26/96	14	11.662						0.066
11/26/96	17	3.136						0.020
11/26/96	18	9.634						0.304
11/26/96	31	11.662						0.039
11/26/96	33	3.238						0.020
11/26/96	35	9.634						0.115
11/26/96	57	2.028	0.003	0.000			0.003	11.945
11/26/96	60	7.099	0.000				0.000	21.770
11/26/96	COMP	96.341						129.571
12/18/96	9	3.931						
12/18/96	11	4.433						0.033

* Blank cells represent BQL results.

NA = Not analyzed

NS = Not Sampled

Table 2: REMOVAL RATES OF CONTAMINANTS

CLIENT: G. E. CELL 46

CLIENT CODE: 2002

ANALYST: T. LONIEWSKI

PROJECT MANGER: M. HOLLAND

FIELD DATA		POUNDS OF CONTAMINANTS PER DAY						
SAMPLE DATE	WELL #	Hydrocarbon Biodegradation	BENZENE	TOLUENE	ET.BENZ.	XYLENES	BTEX	TPH
12/18/96	14	8.113						0.020
12/18/96	17	1.422						
12/18/96	18	5.578						0.141
12/18/96	31	7.099						0.022
12/18/96	33	1.333						
12/18/96	35	7.099						0.008
12/18/96	57	1.521	0.004	0.001	0.000	0.000	0.005	6.048
12/18/96	60	4.564	0.000				0.000	15.209
12/18/96	COMP	65.918						170.001
1/22/97	9	4.422						0.034
1/22/97	11	6.822						0.127
1/22/97	14	6.022						0.169
1/22/97	17	1.788						0.028
1/22/97	18	9.127						12.005
1/22/97	31	4.187						1.012
1/22/97	33	1.223						0.013
1/22/97	35	7.245						0.053
1/22/97	57	2.535	0.014	0.001	0.000	0.001	0.015	13.920
1/22/97	60	9.127	0.002	0.000			0.002	30.418
1/22/97	COMP	84.679	0.006				0.006	150.805
2/11/97	9	2.352						0.137
2/11/97	11	1.741						0.052
2/11/97	14	1.129						0.168
2/11/97	17	0.094						0.038
2/11/97	18	1.607						0.007
2/11/97	31	1.223						0.009
2/11/97	33	0.329						0.042
2/11/97	35	3.623						0.020
2/11/97	57	2.028	0.003	0.001		0.000	0.005	7.059
2/11/97	60	9.127						4.033
2/11/97	COMP	30.674						7.879

* Blank cells represent BQL results.
 NA = Not analyzed
 NS = Not Sampled

3/13/97

Table 3

CUMULATIVE YIELD OF CONTAMINANTS
SOIL VAPOR EXTRACTION SYSTEM - COMPOSITE SAMPLE
G.E. CELL 46: CINCINNATI, OHIO

SAMPLE DATE	BENZENE	TOLUENE	ET. BENZENE	XYLENES	BTEX	TPH	HYDROCARBON BIODEGRADATION
6/13/94	0.00	0.00	0.00	0.00	0.00	0	0
6/13/94	0.01	0.00	0.00	0.00	0.01	1	2
6/13/94	0.04	0.00	0.00	0.01	0.05	6	8
7/20/94	6.34	0.74	0.98	1.38	9.45	1,084	2,276
8/26/94	6.49	0.88	1.17	1.69	10.23	1,314	4,241
9/8/94	6.51	0.89	1.19	1.71	10.31	1,352	4,924
9/22/94	6.51	0.89	1.19	1.71	10.31	1,363	5,677
10/6/94	6.51	0.89	1.19	1.71	10.31	1,374	6,348
12/1/94	6.51	0.89	1.19	1.71	10.31	1,403	8,087
1/11/95	6.51	0.89	1.19	1.71	10.31	1,580	9,909
3/2/95	6.51	0.89	1.19	1.71	10.31	1,796	11,919
3/25/95	6.51	0.89	1.19	1.71	10.31	1,803	12,329
4/24/95	6.51	0.89	1.19	1.71	10.31	1,816	12,943
6/6/95	6.51	0.89	1.19	1.71	10.31	1,829	13,512
8/3/95	6.51	0.89	1.19	1.71	10.31	1,833	14,394
8/3/95	6.51	0.89	1.19	1.71	10.31	1,833	14,395
9/12/95	6.51	0.89	1.19	1.71	10.31	1,834	15,114

All results are reported in pounds.

NA = Not Sampled.

NS = Not Sampled.

3/11/97

Table 3

***CUMULATIVE YIELD OF CONTAMINANTS
SOIL VAPOR EXTRACTION SYSTEM - COMPOSITE SAMPLE
G.E. CELL 46: CINCINNATI, OHIO***

SAMPLE DATE	BENZENE	TOLUENE	ET. BENZENE	XYLENES	BTEX	TPH	HYDROCARBON BIODEGRADATION
10/25/95	6.51	0.89	1.19	1.71	10.31	1,842	16,016
11/8/95	6.51	0.89	1.19	1.71	10.31	1,849	16,217
12/5/95	6.51	0.89	1.19	1.71	10.31	1,866	16,630
1/17/96	6.51	0.95	1.19	1.71	10.36	1,889	NS
2/26/96	6.51	0.95	1.19	1.71	10.36	1,899	16,634
2/26/96	6.51	0.95	1.19	1.71	10.36	1,909	16,639
2/27/96	6.51	0.95	1.19	1.71	10.36	2,031	16,700
4/4/96	6.61	0.95	1.19	1.71	10.46	5,023	18,006
4/4/96	6.61	0.95	1.19	1.71	10.46	5,037	18,008
4/30/96	6.66	1.02	1.19	1.86	10.73	7,458	18,725
6/11/96	6.71	1.06	1.19	1.95	10.92	7,928	18,994
6/25/96	6.79	1.10	1.19	2.01	11.09	8,577	19,561
8/13/96	6.79	1.10	1.19	2.01	11.09	9,004	21,810
9/18/96	6.79	1.10	1.19	2.01	11.09	9,169	23,328
10/17/96	6.79	1.10	1.19	2.03	11.10	9,456	23,980
11/26/96	6.79	1.10	1.19	2.04	11.12	10,077	24,616
12/18/96	6.79	1.10	1.19	2.04	11.12	10,619	24,909

All results are reported in pounds.

NA = Not Sampled.

NS = Not Sampled.

3/11/97

Table 3

***CUMULATIVE YIELD OF CONTAMINANTS
SOIL VAPOR EXTRACTION SYSTEM - COMPOSITE SAMPLE
G.E. CELL 46: CINCINNATI, OHIO***

SAMPLE DATE	BENZENE	TOLUENE	ET. BENZENE	XYLENES	BTEX	TPH	HYDROCARBON BIODEGRADATION
1/22/97	6.81	1.10	1.19	2.04	11.14	11,828	25,477
2/11/97	6.86	1.10	1.19	2.04	11.19	13,112	26,410

All results are reported in pounds.

NA = Not Sampled.

NS = Not Sampled.

3/11/97

ATTACHMENT A

CONTAMINANT YIELD CALCULATION FOR SOIL VAPOR EXTRACTION SYSTEMS

The calculations described below were used to calculate contaminant yields from off-gas concentrations and flow rates. Concentration values were reported as ppm_v (μl/l) for each contaminant, and flows were reported as scfm (ft³/min). These concentration and flow data must be converted for use in Equation 1, to provide mass yield per unit time:

$$CONC \left(\frac{\text{mass}}{\text{volume}} \right) \times FLOW \left(\frac{\text{volume}}{\text{time}} \right) = YIELD \left(\frac{\text{mass}}{\text{time}} \right) \quad \text{EQN 1}$$

Final values will be expressed as pounds per day, which requires a series of units conversions. Since gas phase concentrations are reported in units of volume per volume, it is necessary to convert to a mass-per-volume expression for concentration. First, the ideal gas law is used to determine the number of moles, *n*, in a microliter of gas at 20° C:

$$P \cdot V = n \cdot R \cdot T \quad \text{EQN 2}$$

is rearranged to isolate moles:

$$n = \frac{P \cdot V}{R \cdot T} \quad \text{EQN 3}$$

where:

$$\begin{aligned} P &= 1 \text{ atm} \\ V &= 1 \text{ } \mu\text{l} = 1 \times 10^{-6} \text{ l} \\ R &= 0.08205 \text{ l} \cdot \text{atm} / \text{mol} \cdot \text{K} \\ T &= 20 \text{ } ^\circ\text{C} = 293 \text{ K} \end{aligned}$$

From EQN 3, above:

$$\frac{n}{\mu\text{l}} = \frac{1 \text{ atm} \cdot 1 \times 10^{-6} \frac{\text{l}}{\mu\text{l}}}{0.08205 \frac{\text{l} \cdot \text{atm}}{\text{mol} \cdot \text{K}} \cdot 293 \text{ K}} \quad \text{EQN 4}$$

Therefore, for any ideal gas at 20 °C and 1 atm,

$$\frac{n}{\mu\text{l}} = 4.16 \times 10^{-8} \frac{\text{mol}}{\mu\text{l}} \quad \text{EQN 5}$$

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Now the original concentration value which was expressed in units of $\mu\text{l}_{\text{contam}}$ per liter air (ppm_v) can be converted to moles per liter air:

$$C' \left(\frac{\text{mol}}{\text{l}_{\text{air}}} \right) = C \left(\frac{\mu\text{l}_{\text{contam}}}{\text{l}_{\text{air}}} \right) \times 4.16 \times 10^{-8} \frac{\text{mol}}{\mu\text{l}_{\text{contam}}} \quad \text{EQN 6}$$

The next step is to apply the formula weight, MW, for the compound of interest to convert from moles per μl to grams per l:

$$C'' \left(\frac{\text{g}}{\text{l}_{\text{air}}} \right) = C' \left(\frac{\text{mol}}{\text{l}_{\text{air}}} \right) \times MW \left(\frac{\text{g}}{\text{mol}} \right) \quad \text{EQN 7}$$

Substituting for C' from EQN 6 yields an expression which provides concentration values in units of mass per volume from the analytical result in ppm_v:

$$C'' \left(\frac{\text{g}}{\text{l}_{\text{air}}} \right) = C \left(\frac{\mu\text{l}_{\text{contam}}}{\text{l}_{\text{air}}} \right) \times 4.16 \times 10^{-8} \frac{\text{mol}}{\mu\text{l}_{\text{contam}}} \times MW \left(\frac{\text{g}}{\text{mol}} \right) \quad \text{EQN 8}$$

The remaining steps are simple units conversions. First, convert C'' from g/l_{air} to lb/ft³_{air}:

$$C''' \left(\frac{\text{lb}}{\text{ft}^3} \right) = C'' \left(\frac{\text{g}}{\text{l}_{\text{air}}} \right) \times 0.0022 \frac{\text{lb}}{\text{g}} \times 28.3 \frac{\text{l}_{\text{air}}}{\text{ft}^3} \quad \text{EQN 9}$$

Next, convert flow, Q, from ft³/min as measured in the field, to Q' needed for substitution into EQN 1, in units of ft³/day:

$$Q' \left(\frac{\text{ft}^3}{\text{day}} \right) = Q \left(\frac{\text{ft}^3}{\text{min}} \right) \times 1440 \frac{\text{min}}{\text{day}} \quad \text{EQN 10}$$

Equation 1 can now be restated as follows:

$$\text{YIELD} \left(\frac{\text{lb}}{\text{day}} \right) = Q' \left(\frac{\text{ft}^3}{\text{day}} \right) \times C''' \left(\frac{\text{lb}}{\text{ft}^3} \right) \quad \text{EQN 11}$$

Finally, an equation can be stated which isolates the two measurements, Q (ft³/min) and C (μl/l), and the formula weight of the compound of interest, MW (g/mol), and lumps the conversions from equations 8, 9 and 10 into a single number:

$$\text{YIELD} \left(\frac{\text{lb}}{\text{day}} \right) = Q \left(\frac{\text{ft}^3}{\text{min}} \right) \times C \left(\frac{\mu\text{l}_{\text{contam}}}{\text{l}_{\text{air}}} \right) \times MW \left(\frac{\text{g}}{\text{mol}} \right) \times 3.73 \times 10^{-6} \frac{\text{mol} \times \text{lb} \times \text{l}_{\text{air}} \times \text{min}}{\mu\text{l}_{\text{contam}} \times \text{g} \times \text{ft}^3 \times \text{day}} \quad \text{EQN 12}$$

MWR

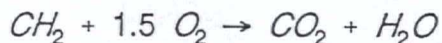
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ATTACHMENT B

BIODEGRADATION YIELD CALCULATION FOR SOIL VAPOR EXTRACTION SYSTEMS

The calculations described below were used to determine biodegradation yields from the soil vapor extraction system, based on differences between carbon dioxide (CO₂) concentrations in the injection and withdrawal air streams. CO₂ concentrations were measured in ppm_v, and air flows were recorded as scfm (ft³/min). These values can be used to calculate the metabolic conversion of petroleum hydrocarbons, given the following assumptions:

1. CO₂ enrichment of the SVE-induced air flow is entirely attributable to biodegradation of petroleum hydrocarbons. This assumption overlooks two potential sources of CO₂: biodegradation of native soil organics, and de-gassing of CO₂-rich groundwater. It also overlooks soil carbonate minerals, which are a potential CO₂ sink. In a site known to contain petroleum hydrocarbons, this error is expected to be small relative to CO₂ production rates.
2. CH₂ is representative of the basic petroleum hydrocarbon carbon-hydrogen ratio. The aerobic respiration of CH₂ is then summarized by the following stoichiometry:



For every CH₂ unit degraded by soil microbes, one CO₂ molecule is added to the soil atmosphere. Therefore, the CO₂ provides a one-to-one molar representation of the metabolic conversion of petroleum hydrocarbon.

The first step in the calculation of biodegradation yield is the conversion of field data for carbon dioxide concentrations from volumetric (ppm_v, or μl CO₂/l_{air}) to molar concentrations (mol CO₂/l_{air}). To do this, the ideal gas law is used to calculate the number of moles, *n*, in a μl of gas at 20° C:

$$P \cdot V = n \cdot R \cdot T \quad \text{EQN 1}$$

rearranged to isolate moles:

$$n_{\text{CO}_2} = \frac{P \cdot V_{\text{CO}_2}}{R \cdot T} \quad \text{EQN 2}$$

where:

$$\begin{aligned} P &= 1 \text{ atm} \\ V_{\text{CO}_2} &= 1 \text{ } \mu\text{l} = 1 \times 10^{-6} \text{ l} \\ R &= 0.08205 \text{ l} \cdot \text{atm} / \text{mol} \cdot \text{K} \\ T &= 20^\circ \text{ C} = 293 \text{ K} \end{aligned}$$

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From EQN 2, above,

$$\frac{n_{CO_2}}{\mu l_{CO_2}} = \frac{1 atm \cdot 1 \times 10^{-6} \frac{l_{CO_2}}{\mu l_{CO_2}}}{0.08205 \frac{l atm}{mol K} \cdot 293 K}$$

EQN 3

Therefore, for CO₂, as an ideal gas at 20° C and 1 atm,

$$\frac{n_{CO_2}}{\mu l_{CO_2}} = 4.16 \times 10^{-8} \frac{mol_{CO_2}}{\mu l_{CO_2}}$$

EQN 4

Now the original concentration value which was expressed in units of μl_{CO₂} per liter air (ppm_v) can be converted to moles per liter air. The new concentration value is labelled as C':

$$C' \left(\frac{mol_{CO_2}}{l_{air}} \right) = C \left(\frac{\mu l_{CO_2}}{l_{air}} \right) \times 4.16 \times 10^{-8} \frac{mol_{CO_2}}{\mu l_{CO_2}}$$

EQN 5

The next step is to apply the formula weight for the compound of interest, to convert from moles per μl to grams per l. Since the CO₂ is assumed to quantitatively represent petroleum hydrocarbon metabolized, and since CH₂ is assumed to be the representative hydrocarbon unit, the molecular weight of CH₂ (14.0 g/mol) will now be substituted for that of CO₂:

$$C'' \left(\frac{g_{CH_2}}{l_{air}} \right) = C' \left(\frac{mol_{CO_2}}{l_{air}} \right) \times 1.0 \frac{mol_{CH_2}}{mol_{CO_2}} \times 14.0 \frac{g_{CH_2}}{mol_{CH_2}}$$

EQN 6

Substituting from EQN 5 for C' in EQN 6 yields an expression which provides concentration values in units of mass CH₂ per volume air from the CO₂ analytical result in ppm_v:

$$C'' \left(\frac{g_{CH_2}}{l_{air}} \right) = C \left(\frac{\mu l_{CO_2}}{l_{air}} \right) \times 4.16 \times 10^{-8} \frac{mol_{CO_2}}{\mu l_{CO_2}} \times 1.0 \frac{mol_{CH_2}}{mol_{CO_2}} \times 14.0 \frac{g_{CH_2}}{mol_{CH_2}}$$

EQN 7

The remaining steps are units conversions. First, convert C'' from g/l_{air} to lb/ft³_{air}:

$$C''' \left(\frac{lb_{CH_2}}{ft^3_{air}} \right) = C'' \left(\frac{g_{CH_2}}{l_{air}} \right) \times 0.0022 \frac{lb_{CH_2}}{g_{CH_2}} \times 28.3 \frac{l_{air}}{ft^3_{air}}$$

EQN 8

Next, convert flow, Q, from ft³/min as measured in the field, to Q' in units of ft³/day needed for calculation of daily hydrocarbon biodegradation yield:

$$Q' \left(\frac{ft^3}{day} \right) = Q \left(\frac{ft^3}{min} \right) \times 1440 \frac{min}{day}$$

EQN 9

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An equation can now be stated which quantifies biodegradation yield as the product of air flow and off-gas metabolite concentrations:

$$BIO\ YIELD\ \left(\frac{lb_{CH_2}}{day}\right) = Q' \left(\frac{ft^3_{air}}{day}\right) \times C''' \left(\frac{lb_{CH_2}}{ft^3_{air}}\right) \quad EQN\ 10$$

Finally, EQN 10 can be restated, isolating the two field measurements, Q (ft³/min) and C (ppm_v CO₂). The balance of the equation lumps the molecular weight for CH₂ and the units conversions from equations 7 through 9:

$$BIO\ \left(\frac{lb_{CH_2}}{day}\right) = Q\ \left(\frac{ft^3_{air}}{min}\right) \times C\ \left(\frac{\mu l_{CO_2}}{l_{air}}\right) \times 5.22 \times 10^{-5} \frac{min \times l_{air} \times mol_{CO_2} \times mol_{CH_2} \times g_{CH_2}}{day \times ft^3_{air} \times \mu l_{CO_2} \times mol_{CO_2} \times mol_{CH_2}} \quad EQN\ 11$$

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GE Aircraft Engines

General Electric Company
One Neumann Way M/D N123
Cincinnati, Ohio 45215-1988
(513) 243-6272

October 16, 1996

Daniel Patulski
USEPA Region V
RCRA Permitting Section
5HR-13
77 West Jackson Boulevard
Chicago, IL 60604

Re: General Electric Company
GE Aircraft Engines
OHD 000 817 312

Dear Mr. Patulski:

Enclosed are the Progress Reports for the Soil Vapor Extraction Systems for the areas near Buildings 46 and 306. The Progress Reports are for the period from March 1, 1996, to August 31, 1996.

If you have any questions, please contact me at (513) 243-6272.

Sincerely,

Gregory H. Jaspers, PE
Sr. Environmental Engineer

cc: W. Killoran
M. Norman, VSSP
J. Boneberg, OBG
C. Kotsko, OEPA
V. Ord, BUSTR
Mike Bono, Chem Risk
B. Spackman, DZI

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DIVISION FRONT OFFICE
Waste, Pesticides & Toxics Division
U.S. EPA - REGION 5

REPORT

**BIANNUAL PROGRESS REPORT
(March 1, 1996 to August 31, 1996)
Building 306, RECO #90076
General Electric Aircraft Engines
Evendale, Ohio**

SUBMITTED TO:

Mr. Greg Jaspers
General Electric
1 Neumann Way
Mail Drop N-123
Cincinnati, Ohio 45215

SUBMITTED BY:

MWR, Inc.
a Division of Envirogen, Inc.
7707 Rickle Road
Lansing, Michigan 48917

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September 1996

MWR

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REPORT

BIANNUAL PROGRESS REPORT
(March 1, 1996 to August 31, 1996)
Building 306, RECO #90076
General Electric Aircraft Engines
Evendale, Ohio

SUBMITTED TO:

Mr. Greg Jaspers
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1 Neumann Way
Mail Drop N-123
Cincinnati, Ohio 45215

SUBMITTED BY:

MWR, Inc.
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7707 Rickle Road
Lansing, Michigan 48917

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September 1996

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A Division of Envirogen, Inc.

INTRODUCTION

General Electric Corporation (GE) has retained MWR Inc. (MWR), a division of Envirogen, Inc., to provide soil vapor extraction (SVE) services at its aircraft engine facility in Evendale, Ohio (RECO Project No. 90076). MWR is currently conducting remedial activities at two separate treatment cells at the GE facility. This document is a six-month, biannual progress report for the cell adjacent to Building 306. The report covers system operations and maintenance for the period from March 1, 1996 through August 31, 1996.

OPERATIONS

As shown in Figure 1, the treatment cell is located along the north side of Building 306 and consists of 46 SVE wells arranged in six rows. The SVE system was installed in early 1993 and subsequently started operating on February 23, 1993. The original well field configuration placed the designated vacuum air extraction and pressurized air injection wells in alternating rows of wells. As described in the previous Biannual Progress Report covering the period from September 1995 to February 1996, the wellfield was reconfigured five times prior to this reporting period to focus treatment to those soils that previously received little air flow.

The SVE system was reconfigured at the end of the previous reporting period (February 1996) by making rows 1 and 3 (wells 21-30, 42, 43, and 45) vacuum withdrawal and row 2 (wells 31-41, 44, and 46) pressure injection. Since the contaminant levels in air samples did increase substantially from the previous sampling event, the system was scheduled at that time to be operated under this configuration until contaminant levels approached a relatively constant level for benzene, toluene, ethylbenzene, and xylenes (BTEX) and total volatile organic compounds (TVOCs). Therefore, the management strategy developed during the previous reporting period was continued into this reporting period.

The site was visited five times during the reporting period by MWR operations personnel. Site visits were performed on April 4, April 30, June 11, June 25, and August 13 of 1996. While on site, MWR personnel serviced the air handling machinery, made adjustments to increase system effectiveness, collected off-gas samples to monitor the volatile organic compound yield of the system, and made miscellaneous repairs to the system.

During the site visit on April 4, 1996, the hour meter was replaced and an automatic restart circuit was installed. The circuit was installed to restart the system automatically following power supply failure or after pump out of the knock-out tank. A full round of air samples were collected for analysis during this visit.

The water storage tank was found to be full upon arrival to the site on April 30, 1996. After being notified of this condition, Mr. Tom Keifer of Day & Zimmerman

made arrangements to have the water pumped from the storage tank and be properly disposed. The system was shut down while arrangements were made to pump the water. A full round of air samples were collected before leaving the site for analysis of BTEX and TVOCs. Mr. Keifer restarted the system following pump out.

Upon arrival to the site on June 11, 1996, the SVE system was discovered to be down due to a full knock-out tank. Process water was manually pumped from the knock-out tank to the water storage tank. The SVE system was restarted but continually produced water during operation. The system was observed to be not automatically pumping water from the knock-out tank to the water storage tank as designed. Therefore, the system shut down automatically during operations when the knock-out tank became full, and the water was again manually pumped to the water storage tank. The SVE system was again restarted in an effort to clear the lines of water, but the system again continually produced water during operation. Water was once again manually pumped to the water storage tank. Since the water storage tank was nearly full by this time, Mr. Keifer was notified of the condition so that he could make arrangements to properly dispose of the water. Heavy precipitation experienced in the area along with corresponding high groundwater elevations restricted the SVE system from effectively transferring air through the treatment volume. Therefore, no off-gas samples were collected and the SVE system was shut down before leaving the site.

During the site visit on June 25, 1996, the piping and effluent stack on the discharge side of the vacuum blower was replaced since the generated heat had caused the piping to deform. The SVE system was restarted but continually produced water during operation. Water from the knock-out tank was manually pumped to the water storage tank, and the float switch for the water storage tank was replaced. Since high groundwater elevations restricted the SVE system from effectively transferring air through the treatment volume, no off-gas samples were collected and the SVE system was shut down before leaving the site.

Process water was manually pumped out of the water storage tank during the site visit on August 13, 1996. The water transfer hose connecting the knock-out tank to the water storage tank was secured and new belts were installed on the SVE unit.

The SVE system was restarted but again continually produced water during operation. Since high groundwater elevations restricted the SVE system from effectively transferring air through the treatment volume, no off-gas samples were collected and the SVE system was shut down before leaving the site.

A total of eight (8) air samples were collected during the reporting period. Samples were collected from each sample tap on the extraction manifold (plus at least one total system sample) in two-liter Tedlar[®] gas sampling bags. Each bag was purged three times with the off-gas stream to be sampled prior to actual sample collection. A total system sample was collected by sampling the combined flow of the extraction manifold into one sample bag. Collected gas samples were returned to the MWR Organics Laboratory for analysis by gas chromatography for the presence BTEX and TVOCs. Data are reported in parts of contaminants per million parts of air (ppm_v).

ENHANCED VOLATILIZATION RESULTS

Figure 2 illustrates the off-gas concentrations in the composite sample since start-up of the system (February 23, 1993) through August 31, 1996. Concentrations have remained at or near detection limits for the BTEX (0.05 ppm), and have fluctuated throughout operation for the TVOCs. Estimated TVOC concentrations of composite samples have ranged from the detection limit (1.0 ppm) to 6.8 ppm during the reporting period.

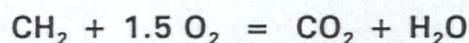
Table 1 contains the off-gas concentrations for the samples collected during this reporting period. A majority of the off-gas samples obtained during this period did not contain BTEX compounds at levels above the detection limit (0.05 ppm), but concentrations have been as high as 1.2 ppm (taken from wells 42, 43, and 45 on April 30, 1996). Estimated TVOC concentrations have ranged from below the detection limit (1.0 ppm) to 9.6 ppm in samples collected during this period.

System off-gas yields derived from the off-gas data for the reporting period were calculated using the methods outlined in Attachment A. The yields were calculated using the data of the composite samples. The various flow rates required in the calculations are tabulated in Table 1. Table 2 lists the results of the yield calculations which represent the amount of contaminants captured per day of operation at the concentrations tabulated in Table 1 on the respective sampling dates. The yield data represent the removal rate through volatilization of the various target compounds during this reporting period by the SVE system. Table 3 tabulates the cumulative yield of the SVE system since start-up. Approximately 726 pounds of total volatile organic compounds have been removed from the soils within the treatment cell since system start-up. Of these, approximately 26 pounds have been BTEX compounds. Since the total size of the treatment cell is approximately 14,500 cubic yards, or about 40.6 million pounds of soil, then the 726 pound removal of contaminants represents a theoretical average reduction in contaminant concentration of 18 ppm. Using the same methodology, the theoretical average reduction of BTEX compounds is approximately 0.7 ppm.

Figure 3 shows the cumulative yield curve of the system since start-up. The slope of the TVOC curve increased following the wellfield reconfiguration performed in February 1996 and was approximately constant until the SVE system shut down between April 30 and June 11, 1996.

BIODEGRADATION RESULTS

Carbon dioxide (CO₂) levels in the off-gas samples were measured to track biodegradation of fuels by indigenous soil microorganisms. Normal concentrations of CO₂ in the atmosphere are approximately 300 ppm. Elevated CO₂ concentrations in the treatment cell indicate biological activity in the soil. The CO₂ concentrations will initially drop off during the early stages of SVE as the soil air is initially replaced with atmospheric air containing normal oxygen levels. As the soil microfauna is stimulated by the oxygen in normal air, the CO₂ will again rise above background. The microbes consume petroleum hydrocarbons in the soil converting the compounds to CO₂ and water following the general reaction below:



Removal of contaminants by biological degradation was calculated as outlined in **Attachment B**. The CO₂ concentrations measured during the reporting period are shown in **Table 1** for the corresponding sampling dates and withdrawal locations. **Table 2** tabulates the daily system yield due to biodegradation which represent yields per day during the individual sampling periods. **Table 3** lists the cumulative yield of contaminant compound removal by biodegradation. Approximately 34,100 pounds of hydrocarbons have been removed from the treatment cell through metabolism by the soil microorganisms since project start-up. Approximately 950 pounds have been removed during this reporting period. The total reduction in contaminants in the treatment cell containing approximately 40.6 million pounds of soil amounts to a theoretical average reduction in concentration of approximately 840 ppm.

Figure 4 is the cumulative mass biodegradation (yield) curve since project start-up. The slope of the curve indicates an increased rate of contaminant removal by biodegradation since the wellfield was reconfigured in February 1996. This rate of removal remained approximately constant until the SVE system shut down between April 30 and June 11, 1996.

FUTURE ACTIVITIES

As discussed in correspondence from M. Holland-MWR to G. Jaspers-GE, dated May 14, 1996, MWR has determined that the SVE system currently operating at Cell 306 to capture contaminants from vadose zone soils has reached its practical and economical limits of performance. Based on the SVE system design, soil analytical results, and an investigation of soil stratigraphy, the upper vadose zone underlying the treatment area at Cell 306 is experiencing inadequate air flow to remediate the remaining contaminated soils in the near future.

MWR has recommended that horizontal SVE wells be installed to treat remaining contaminants in the upper vadose. However, since General Electric is presently conducting a Risk Assessment, horizontal well installation has been postponed until it is determined if additional treatment is actually required. The SVE system at Cell 306 will remain shutdown until further notice by General Electric.

FIGURES

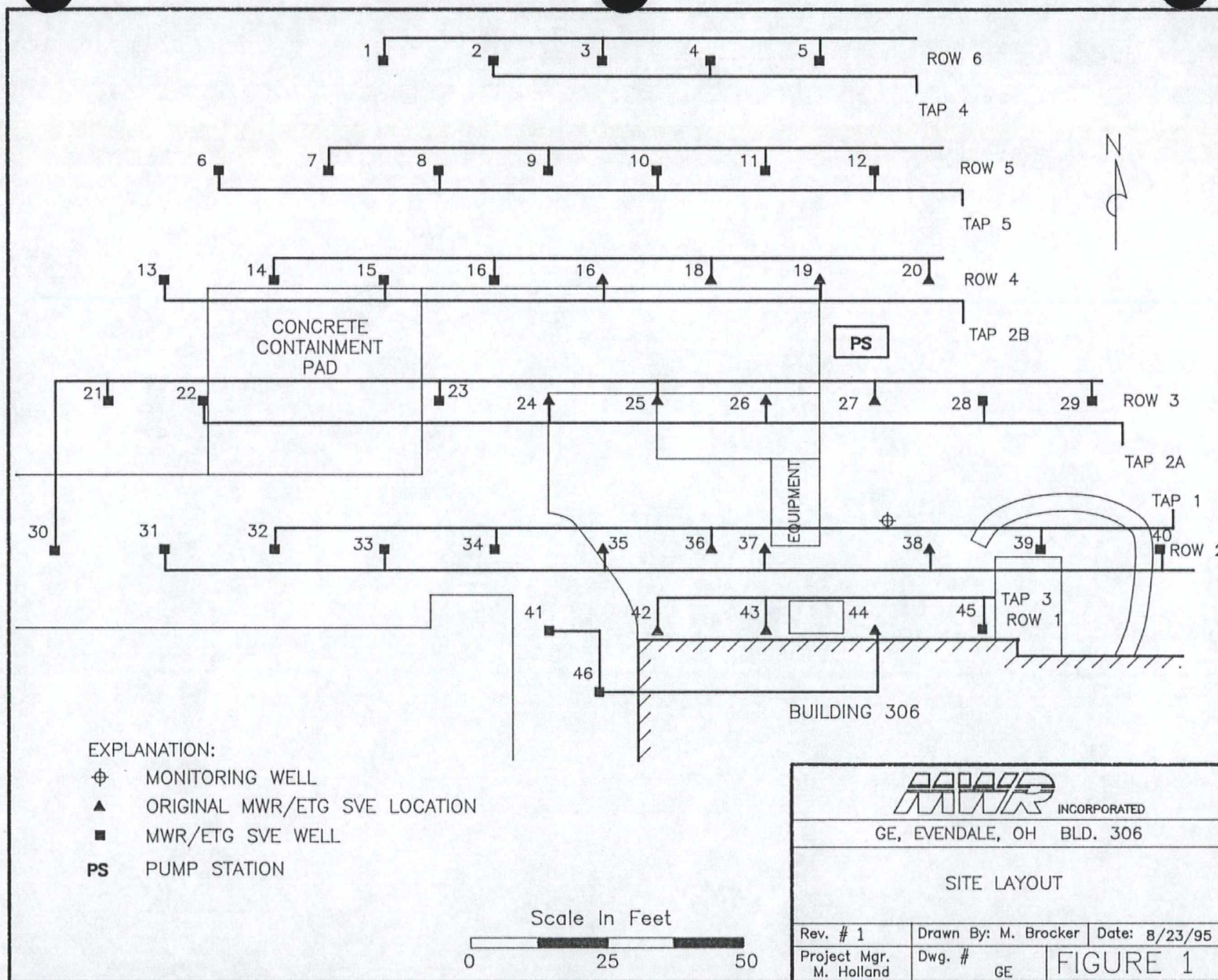
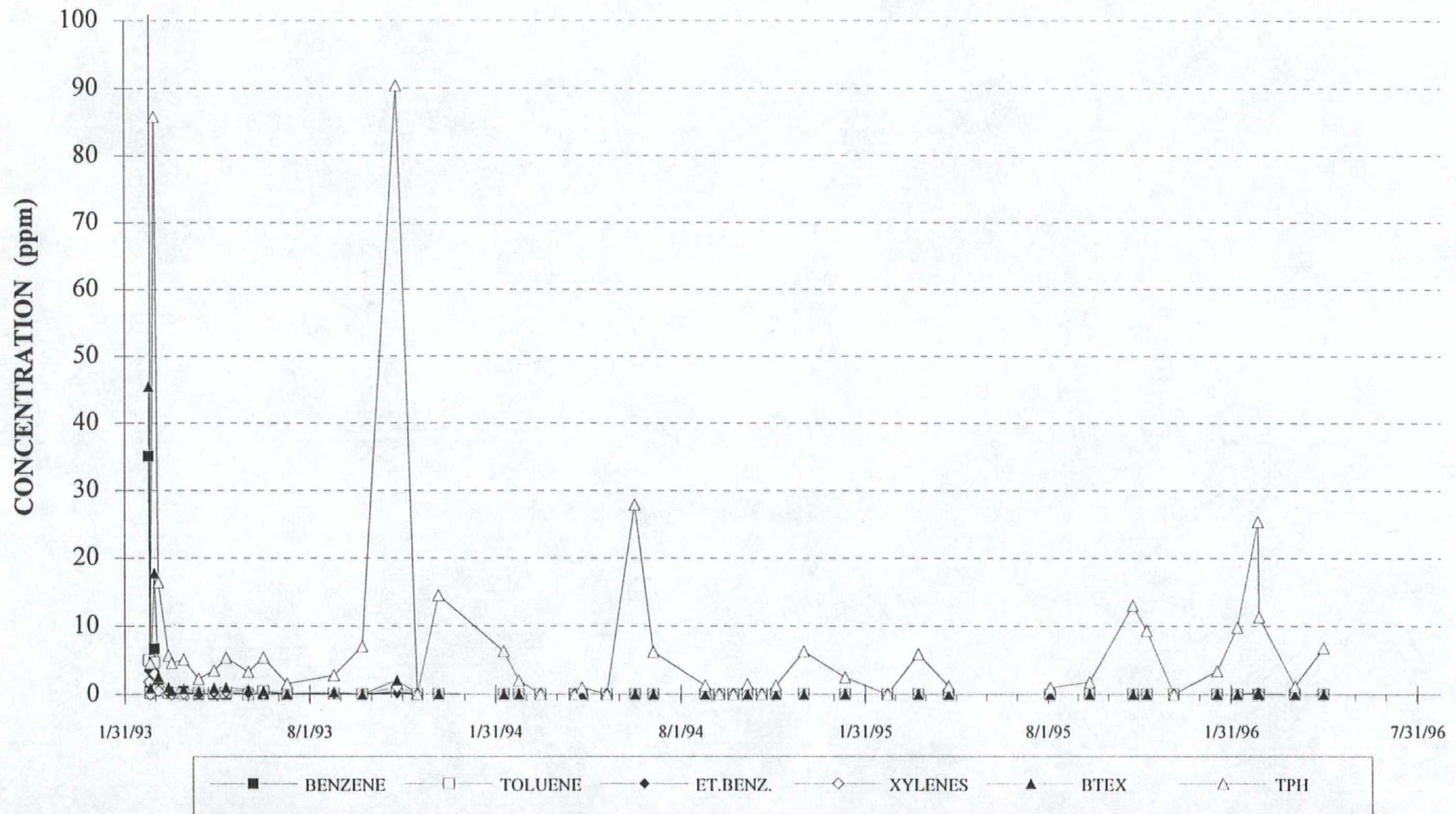


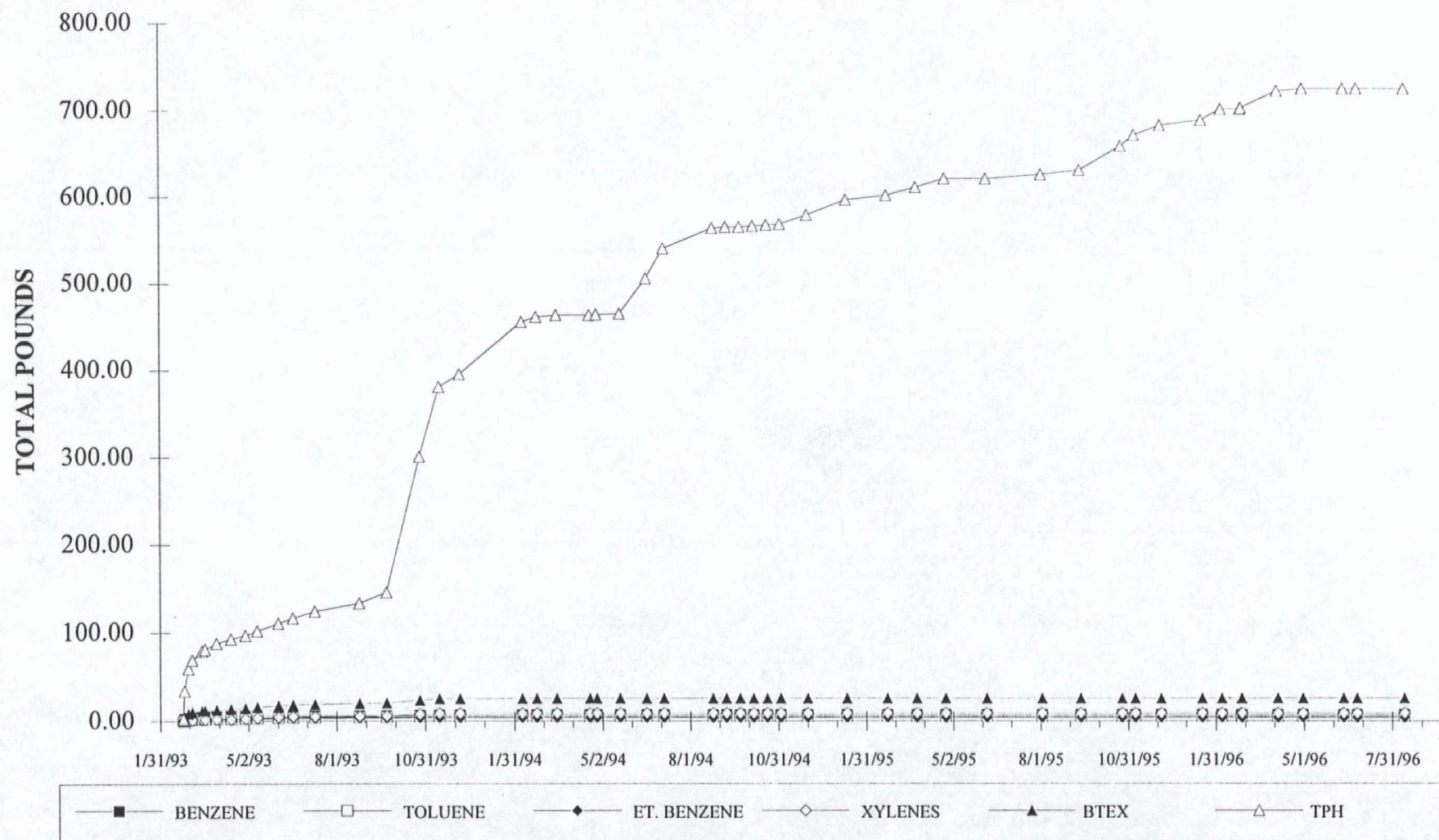
Figure 2
OFF - GAS CONCENTRATION OF CONTAMINANTS
SOIL VAPOR EXTRACTION SYSTEM - COMPOSITE SAMPLE
G.E. BLDG. 306: CINCINNATI, OHIO



TPH detection limit = 1 ppm
 BTEX detection limit = .05 ppm

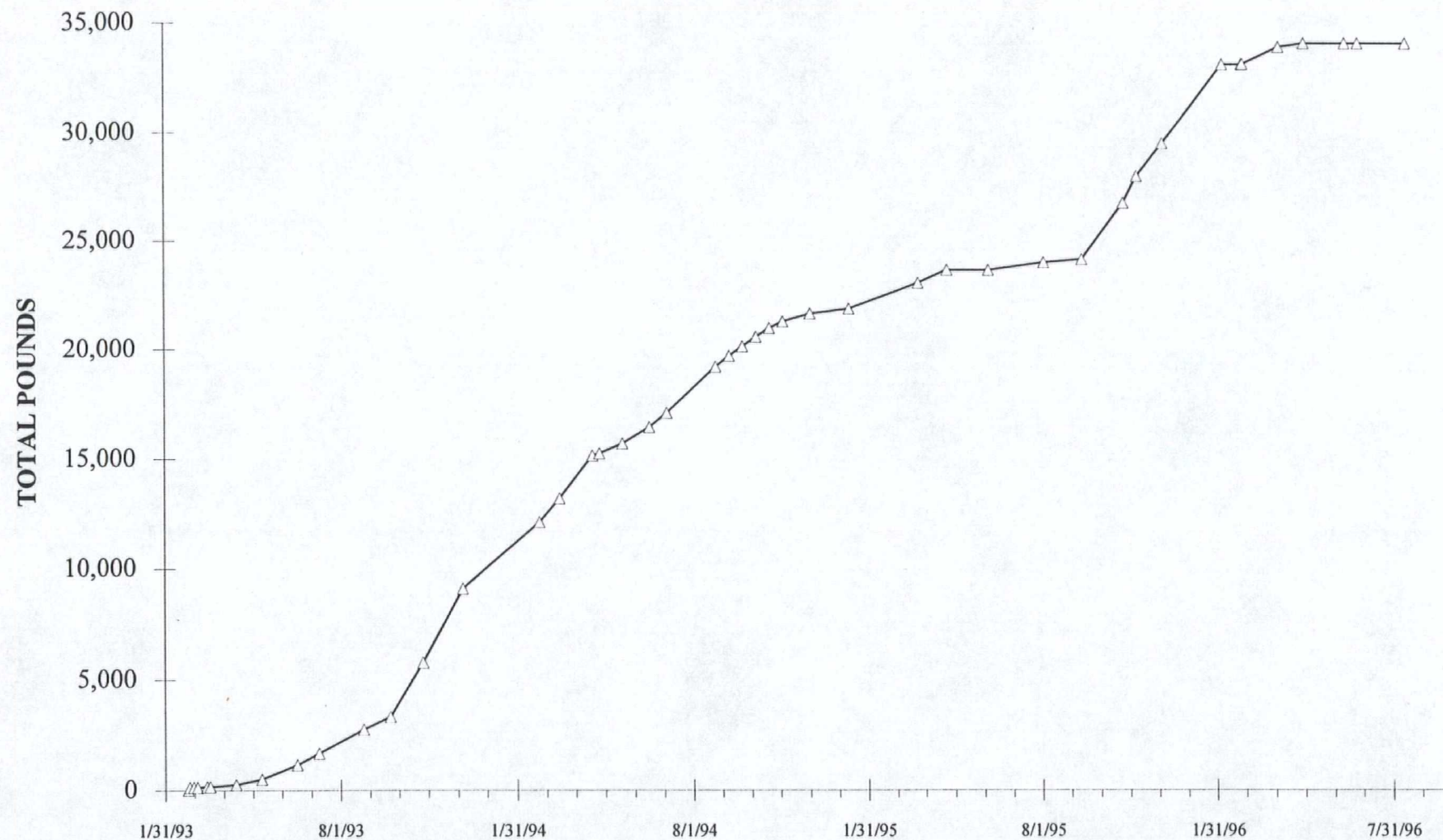
2/23/93 Composite sample has a THP concentration of 335.5 ppm

Figure 3
OFF - GAS CUMULATIVE YIELD OF VOCs
SOIL VAPOR EXTRACTION SYSTEM - COMPOSITE SAMPLE
G.E. Bldg. 306: CINCINNATI, OHIO



9/13/96

Figure 4
CUMULATIVE YIELD OF HYDROCARBON BIODEGRADATION
SOIL VAPOR EXTRACTION SYSTEM - COMPOSITE SAMPLE
G.E. Bldg. 306: CINCINNATI, OHIO



9/13/96

TABLES

Table 1: OFF - GAS CONCENTRATIONS

CLIENT: G. E. BUILDING # 306

CLIENT CODE: 2002

ANALYST: T. LONIEWSKI

PROJECT MANGER: M. HOLLAND

FIELD DATA					LAB DATA (ppm)				
SAMPLE DATE	SAMPLE #	WELL #	FLOW (CFM)	C02 (PPM)	BENZENE	TOLUENE	ET.BENZ.	XYLENES	TPH
4/4/96	COMP	COMP 306	280	2,800					1.20
4/4/96	Sample 1	21, 23, 25, 27, 29	100	5,000					<1.0
4/4/96	Sample 2	22, 24, 26, 28,	95	1,350					<1.0
4/4/96	Sample 3	42, 43, 45	85	1,650			0.05	0.06	<1.0
4/30/96	COMP	COMP 306	270	1,500				0.06	6.80
4/30/96	Sample 1	21, 23, 25, 27, 29	70	1,900					2.60
4/30/96	Sample 2	22, 24, 26, 28,	100	1,350				0.05	5.50
4/30/96	Sample 3	42, 43, 45	100	1,400		0.06		0.06	9.60
6/11/96	COMP	COMP 306	NS	NS	NS	NS	NS	NS	NS
6/25/96	COMP	COMP 306	NS	NS	NS	NS	NS	NS	NS
8/13/96	COMP	COMP 306	NS	NS	NS	NS	NS	NS	NS

* Blank cells represent BQL results.

NA = Not Analyzed

NS = Not Sampled

Table 2: REMOVAL RATES OF CONTAMINANTS

CLIENT: G. E. BUILDING # 306

CLIENT CODE: 2002

ANALYST: T. LONIEWSKI

PROJECT MANGER: M. HOLLAND

FIELD DATA		POUNDS OF CONTAMINANTS PER DAY					
SAMPLE DATE	WELL #	Hydrocarbon Biodegradation	BENZENE	TOLUENE	ET.BENZ.	XYLENES	TPH
4/4/96	COMP 306	36.59					0.13
4/4/96	21, 23, 25, 27, 29	24.57					
4/4/96	22, 24, 26, 28,	5.21					
4/4/96	42, 43, 45	6.00			0.00	0.00	
4/30/96	COMP 306	16.94				0.01	0.69
4/30/96	21, 23, 25, 27, 29	5.85					0.07
4/30/96	22, 24, 26, 28,	5.49				0.00	0.21
4/30/96	42, 43, 45	5.75		0.00		0.00	0.36
6/11/96	COMP 306	NS	NS	NS	NS	NS	NS
6/25/96	COMP 306	NS	NS	NS	NS	NS	NS
8/13/96	COMP 306	NS	NS	NS	NS	NS	NS

* Blank cells represent BQL results.

NA = Not Analyzed

NS = Not Sampled

Table 3
CUMULATIVE YIELD OF CONTAMINANTS
SOIL VAPOR EXTRACTION SYSTEM - COMPOSITE SAMPLE
G.E. BLDG. 306: CINCINNATI, OHIO

SAMPLE DATE	BENZENE	TOLUENE	ET. BENZENE	XYLENES	BTEX	TPH	HYDROCARBON BIODEGRADATION
2/23/93	0.21	0.04	0.03	0.02	0.29	2.62	11
2/25/93	2.81	0.48	0.40	0.20	3.90	34.48	137
3/1/93	4.39	1.75	1.46	1.11	8.72	59.88	139
3/5/93	4.95	2.21	1.85	1.46	10.47	69.46	141
3/15/93	5.43	2.59	2.17	1.88	12.07	79.81	154
3/18/93	5.48	2.65	2.23	1.93	12.28	81.25	163
3/30/93	5.84	2.80	2.49	2.02	13.16	88.07	NS
4/14/93	6.08	2.95	2.59	2.35	13.97	92.92	258
4/29/93	6.08	3.19	2.72	3.02	15.01	97.00	NS
5/11/93	6.08	3.46	2.99	3.63	16.16	102.00	505
6/2/93	6.08	3.73	3.40	4.67	17.89	110.56	NS
6/17/93	6.08	4.02	3.49	5.14	18.73	116.67	1,164
7/10/93	6.08	4.45	3.49	5.36	19.38	124.21	1,675
8/25/93	6.17	4.63	3.60	6.00	20.40	133.48	2,762
9/22/93	6.22	4.73	3.67	6.26	20.87	145.88	3,327
10/26/93	6.77	5.26	3.97	8.10	24.10	300.98	5,782
11/15/93	7.09	5.55	4.14	9.12	25.91	381.43	NS
12/6/93	7.13	5.55	4.14	9.12	25.95	395.69	9,101
2/8/94	7.27	5.55	4.14	9.12	26.09	456.09	NS
2/23/94	7.27	5.55	4.14	9.12	26.09	461.92	12,120
3/16/94	7.27	5.55	4.14	9.12	26.09	464.08	13,202
4/19/94	7.27	5.55	4.14	9.12	26.09	464.08	15,160

Table 3
CUMULATIVE YIELD OF CONTAMINANTS
SOIL VAPOR EXTRACTION SYSTEM - COMPOSITE SAMPLE
G.E. BLDG. 306: CINCINNATI, OHIO

SAMPLE DATE	BENZENE	TOLUENE	ET. BENZENE	XYLENES	BTEX	TPH	HYDROCARBON BIODEGRADATION
4/26/94	7.27	5.55	4.14	9.12	26.09	464.41	15,263
5/20/94	7.27	5.55	4.14	9.12	26.09	465.53	15,699
6/17/94	7.27	5.55	4.14	9.12	26.09	506.46	16,446
7/5/94	7.27	5.55	4.14	9.12	26.09	540.89	17,100
8/25/94	7.27	5.55	4.14	9.12	26.09	564.59	19,216
9/8/94	7.27	5.55	4.14	9.12	26.09	565.59	19,713
9/22/94	7.27	5.55	4.14	9.12	26.09	565.59	20,151
10/6/94	7.27	5.55	4.14	9.12	26.09	566.83	20,589
10/20/94	7.27	5.55	4.14	9.12	26.09	568.07	20,993
11/3/94	7.27	5.55	4.14	9.12	26.09	568.90	21,297
12/1/94	7.27	5.55	4.14	9.12	26.09	579.54	21,664
1/11/95	7.27	5.55	4.14	9.12	26.09	597.22	21,888
2/22/95	7.27	5.55	4.14	9.12	26.09	602.36	NS
3/25/95	7.27	5.55	4.14	9.12	26.09	611.63	23,078
4/24/95	7.27	5.55	4.14	9.12	26.09	621.51	23,675
6/6/95	7.27	5.55	4.14	9.12	26.09	621.51	23,676
8/3/95	7.27	5.55	4.14	9.12	26.09	626.64	24,033
9/12/95	7.27	5.55	4.14	9.12	26.09	631.48	24,180
10/25/95	7.27	5.55	4.14	9.12	26.09	659.50	26,768
11/8/95	7.27	5.55	4.14	9.12	26.09	672.26	28,006
12/5/95	7.27	5.55	4.14	9.12	26.09	683.32	29,521
1/17/96	7.27	5.55	4.14	9.12	26.09	689.47	NA

Table 3
CUMULATIVE YIELD OF CONTAMINANTS
SOIL VAPOR EXTRACTION SYSTEM - COMPOSITE SAMPLE
G.E. BLDG. 306: CINCINNATI, OHIO

SAMPLE DATE	BENZENE	TOLUENE	ET. BENZENE	XYLENES	BTEX	TPH	HYDROCARBON BIODEGRADATION
2/6/96	7.27	5.55	4.14	9.12	26.09	702.02	33,143
2/26/96	7.27	5.55	4.14	9.13	26.09	702.18	33,148
2/27/96	7.27	5.55	4.15	9.14	26.11	703.78	33,158
4/4/96	7.27	5.55	4.15	9.29	26.26	723.45	33,938
4/30/96	7.27	5.55	4.15	9.31	26.28	726.00	34,105
6/11/96	7.27	5.55	4.15	9.31	26.28	726.00	34,105
6/25/96	7.27	5.55	4.15	9.31	26.28	726.00	34,105
8/13/96	7.27	5.55	4.15	9.31	26.28	726.00	34,105

ATTACHMENT A

CONTAMINANT YIELD CALCULATION FOR SOIL VAPOR EXTRACTION SYSTEMS

The calculations described below were used to calculate contaminant yields from off-gas concentrations and flow rates. Concentration values were reported as ppm_v (μl/l) for each contaminant, and flows were reported as scfm (ft³/min). These concentration and flow data must be converted for use in Equation 1, to provide mass yield per unit time:

$$CONC \left(\frac{\text{mass}}{\text{volume}} \right) \times FLOW \left(\frac{\text{volume}}{\text{time}} \right) = YIELD \left(\frac{\text{mass}}{\text{time}} \right) \quad \text{EQN 1}$$

Final values will be expressed as pounds per day, which requires a series of units conversions. Since gas phase concentrations are reported in units of volume per volume, it is necessary to convert to a mass-per-volume expression for concentration. First, the ideal gas law is used to determine the number of moles, *n*, in a microliter of gas at 20° C:

$$P \cdot V = n \cdot R \cdot T \quad \text{EQN 2}$$

is rearranged to isolate moles:

$$n = \frac{P \cdot V}{R \cdot T} \quad \text{EQN 3}$$

where:

$$\begin{aligned} P &= 1 \text{ atm} \\ V &= 1 \text{ } \mu\text{l} = 1 \times 10^{-6} \text{ l} \\ R &= 0.08205 \text{ l} \cdot \text{atm} / \text{mol} \cdot \text{K} \\ T &= 20 \text{ } ^\circ\text{C} = 293 \text{ K} \end{aligned}$$

From EQN 3, above:

$$\frac{n}{\mu\text{l}} = \frac{1 \text{ atm} \cdot 1 \times 10^{-6} \frac{\text{l}}{\mu\text{l}}}{0.08205 \frac{\text{l} \cdot \text{atm}}{\text{mol} \cdot \text{K}} \cdot 293 \text{ K}} \quad \text{EQN 4}$$

Therefore, for any ideal gas at 20 °C and 1 atm,

$$\frac{n}{\mu\text{l}} = 4.16 \times 10^{-8} \frac{\text{mol}}{\mu\text{l}} \quad \text{EQN 5}$$

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Now the original concentration value which was expressed in units of $\mu\text{l}_{\text{contam}}$ per liter air (ppm_v) can be converted to moles per liter air:

$$C' \left(\frac{\text{mol}}{\text{l}_{\text{air}}} \right) = C \left(\frac{\mu\text{l}_{\text{contam}}}{\text{l}_{\text{air}}} \right) \times 4.16 \times 10^{-8} \frac{\text{mol}}{\mu\text{l}_{\text{contam}}} \quad \text{EQN 6}$$

The next step is to apply the formula weight, MW, for the compound of interest to convert from moles per μl to grams per l:

$$C'' \left(\frac{\text{g}}{\text{l}_{\text{air}}} \right) = C' \left(\frac{\text{mol}}{\text{l}_{\text{air}}} \right) \times MW \left(\frac{\text{g}}{\text{mol}} \right) \quad \text{EQN 7}$$

Substituting for C' from EQN 6 yields an expression which provides concentration values in units of mass per volume from the analytical result in ppm_v :

$$C'' \left(\frac{\text{g}}{\text{l}_{\text{air}}} \right) = C \left(\frac{\mu\text{l}_{\text{contam}}}{\text{l}_{\text{air}}} \right) \times 4.16 \times 10^{-8} \frac{\text{mol}}{\mu\text{l}_{\text{contam}}} \times MW \left(\frac{\text{g}}{\text{mol}} \right) \quad \text{EQN 8}$$

The remaining steps are simple units conversions. First, convert C'' from g/l_{air} to $\text{lb/ft}^3_{\text{air}}$:

$$C''' \left(\frac{\text{lb}}{\text{ft}^3} \right) = C'' \left(\frac{\text{g}}{\text{l}_{\text{air}}} \right) \times 0.0022 \frac{\text{lb}}{\text{g}} \times 28.3 \frac{\text{l}_{\text{air}}}{\text{ft}^3} \quad \text{EQN 9}$$

Next, convert flow, Q , from ft^3/min as measured in the field, to Q' needed for substitution into EQN 1, in units of ft^3/day :

$$Q' \left(\frac{\text{ft}^3}{\text{day}} \right) = Q \left(\frac{\text{ft}^3}{\text{min}} \right) \times 1440 \frac{\text{min}}{\text{day}} \quad \text{EQN 10}$$

Equation 1 can now be restated as follows:

$$\text{YIELD} \left(\frac{\text{lb}}{\text{day}} \right) = Q' \left(\frac{\text{ft}^3}{\text{day}} \right) \times C''' \left(\frac{\text{lb}}{\text{ft}^3} \right) \quad \text{EQN 11}$$

Finally, an equation can be stated which isolates the two measurements, Q (ft^3/min) and C (μl), and the formula weight of the compound of interest, MW (g/mol), and lumps the conversions from equations 8, 9 and 10 into a single number:

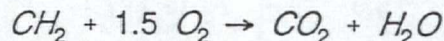
$$\text{YIELD} \left(\frac{\text{lb}}{\text{day}} \right) = Q \left(\frac{\text{ft}^3}{\text{min}} \right) \times C \left(\frac{\mu\text{l}_{\text{contam}}}{\text{l}_{\text{air}}} \right) \times MW \left(\frac{\text{g}}{\text{mol}} \right) \times 3.73 \times 10^{-6} \frac{\text{mol} \times \text{lb} \times \text{l}_{\text{air}} \times \text{min}}{\mu\text{l}_{\text{contam}} \times \text{g} \times \text{ft}^3 \times \text{day}} \quad \text{EQN 12}$$

ATTACHMENT B

BIODEGRADATION YIELD CALCULATION FOR SOIL VAPOR EXTRACTION SYSTEMS

The calculations described below were used to determine biodegradation yields from the soil vapor extraction system, based on differences between carbon dioxide (CO₂) concentrations in the injection and withdrawal air streams. CO₂ concentrations were measured in ppm_v, and air flows were recorded as scfm (ft³/min). These values can be used to calculate the metabolic conversion of petroleum hydrocarbons, given the following assumptions:

1. CO₂ enrichment of the SVE-induced air flow is entirely attributable to biodegradation of petroleum hydrocarbons. This assumption overlooks two potential sources of CO₂: biodegradation of native soil organics, and de-gassing of CO₂-rich groundwater. It also overlooks soil carbonate minerals, which are a potential CO₂ sink. In a site known to contain petroleum hydrocarbons, this error is expected to be small relative to CO₂ production rates.
2. CH₂ is representative of the basic petroleum hydrocarbon carbon-hydrogen ratio. The aerobic respiration of CH₂ is then summarized by the following stoichiometry:



For every CH₂ unit degraded by soil microbes, one CO₂ molecule is added to the soil atmosphere. Therefore, the CO₂ provides a one-to-one molar representation of the metabolic conversion of petroleum hydrocarbon.

The first step in the calculation of biodegradation yield is the conversion of field data for carbon dioxide concentrations from volumetric (ppm_v, or μlCO₂/l_{air}) to molar concentrations (mol CO₂/l_{air}). To do this, the ideal gas law is used to calculate the number of moles, n, in a μl of gas at 20° C:

$$P \cdot V = n \cdot R \cdot T \quad \text{EQN 1}$$

rearranged to isolate moles:

$$n_{\text{CO}_2} = \frac{P \cdot V_{\text{CO}_2}}{R \cdot T} \quad \text{EQN 2}$$

where:

$$\begin{aligned} P &= 1 \text{ atm} \\ V_{\text{CO}_2} &= 1 \text{ } \mu\text{l} = 1 \times 10^{-6} \text{ l} \\ R &= 0.08205 \text{ l} \cdot \text{atm} / \text{mol} \cdot \text{K} \\ T &= 20^\circ \text{ C} = 293 \text{ K} \end{aligned}$$



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From EQN 2, above,

$$\frac{n_{CO_2}}{\mu l_{CO_2}} = \frac{1 atm \cdot 1 \times 10^{-6} \frac{l_{CO_2}}{\mu l_{CO_2}}}{0.08205 \frac{l atm}{mol \cdot K} \cdot 293 K} \quad \text{EQN 3}$$

Therefore, for CO₂, as an ideal gas at 20° C and 1 atm,

$$\frac{n_{CO_2}}{\mu l_{CO_2}} = 4.16 \times 10^{-8} \frac{mol_{CO_2}}{\mu l_{CO_2}} \quad \text{EQN 4}$$

Now the original concentration value which was expressed in units of μl_{CO₂} per liter air (ppm_v) can be converted to moles per liter air. The new concentration value is labelled as C':

$$C' \left(\frac{mol_{CO_2}}{l_{air}} \right) = C \left(\frac{\mu l_{CO_2}}{l_{air}} \right) \times 4.16 \times 10^{-8} \frac{mol_{CO_2}}{\mu l_{CO_2}} \quad \text{EQN 5}$$

The next step is to apply the formula weight for the compound of interest, to convert from moles per μl to grams per l. Since the CO₂ is assumed to quantitatively represent petroleum hydrocarbon metabolized, and since CH₂ is assumed to be the representative hydrocarbon unit, the molecular weight of CH₂ (14.0 g/mol) will now be substituted for that of CO₂:

$$C'' \left(\frac{g_{CH_2}}{l_{air}} \right) = C' \left(\frac{mol_{CO_2}}{l_{air}} \right) \times 1.0 \frac{mol_{CH_2}}{mol_{CO_2}} \times 14.0 \frac{g_{CH_2}}{mol_{CH_2}} \quad \text{EQN 6}$$

Substituting from EQN 5 for C' in EQN 6 yields an expression which provides concentration values in units of mass CH₂ per volume air from the CO₂ analytical result in ppm_v:

$$C'' \left(\frac{g_{CH_2}}{l_{air}} \right) = C \left(\frac{\mu l_{CO_2}}{l_{air}} \right) \times 4.16 \times 10^{-8} \frac{mol_{CO_2}}{\mu l_{CO_2}} \times 1.0 \frac{mol_{CH_2}}{mol_{CO_2}} \times 14.0 \frac{g_{CH_2}}{mol_{CH_2}} \quad \text{EQN 7}$$

The remaining steps are units conversions. First, convert C'' from g/l_{air} to lb/ft³_{air}:

$$C''' \left(\frac{lb_{CH_2}}{ft^3_{air}} \right) = C'' \left(\frac{g_{CH_2}}{l_{air}} \right) \times 0.0022 \frac{lb_{CH_2}}{g_{CH_2}} \times 28.3 \frac{l_{air}}{ft^3_{air}} \quad \text{EQN 8}$$

Next, convert flow, Q, from ft³/min as measured in the field, to Q' in units of ft³/day needed for calculation of daily hydrocarbon biodegradation yield:

$$Q' \left(\frac{ft^3}{day} \right) = Q \left(\frac{ft^3}{min} \right) \times 1440 \frac{min}{day} \quad \text{EQN 9}$$

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An equation can now be stated which quantifies biodegradation yield as the product of air flow and off-gas metabolite concentrations:

$$BIO\ YIELD\ \left(\frac{lb_{CH_2}}{day}\right) = Q' \left(\frac{ft^3_{air}}{day}\right) \times C''' \left(\frac{lb_{CH_2}}{ft^3_{air}}\right) \quad EQN\ 10$$

Finally, EQN 10 can be restated, isolating the two field measurements, Q (ft³/min) and C (ppm_v CO₂). The balance of the equation lumps the molecular weight for CH₂ and the units conversions from equations 7 through 9:

$$BIO\ \left(\frac{lb_{CH_2}}{day}\right) = Q\ \left(\frac{ft^3_{air}}{min}\right) \times C\ \left(\frac{\mu l_{CO_2}}{l_{air}}\right) \times 5.22 \times 10^{-5} \frac{min \times l_{air} \times mol_{CO_2} \times mol_{CH_2} \times g_{CH_2}}{day \times ft^3_{air} \times \mu l_{CO_2} \times mol_{CO_2} \times mol_{CH_2}} \quad EQN\ 11$$

REPORT

BIANNUAL PROGRESS REPORT
(March 1, 1996 to August 31, 1996)
Test Cell 46, RECO #90076
General Electric Aircraft Engines
Evendale, Ohio

SUBMITTED TO:

Mr. Greg Jaspers
General Electric
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Mail Drop N-123
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SUBMITTED BY:

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September 1996

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A Division of Envirogen, Inc.

INTRODUCTION

General Electric Corporation (GE) has retained MWR Inc. (MWR), a division of Envirogen, Inc., to provide soil vapor extraction (SVE) services at its aircraft engine facility in Evendale, Ohio (RECO Project No. 90076). MWR is currently conducting remedial activities at two separate treatment cells at the GE facility. This document is a six-month, biannual progress report for the cell referred to as Test Cell 46, adjacent to Buildings 439 and 437 (Figure 1). The report covers system operations and maintenance for the period from March 1, 1996 through August 31, 1996.

OPERATIONS

As shown in **Figure 1**, the treatment cell is located along the west sides of Buildings 439 and 437 and extends in a westerly direction under the adjacent roadway toward the air cooler and gas compressor. Installed in mid-1994 after remediation activities were completed at Building 301, the system at Test Cell 46 consists of 48 SVE wells distributed throughout the treatment area. Operations began on June 13, 1994 with the original well field configuration having SVE wells 9-11, 14-20, and 30-34 dedicated to the vacuum extraction of contaminants. Vacuum extraction wells 50-63 were added to the system one month after initial start-up, making a total of 30 vacuum extraction wells. Air was injected under pressure through the remaining 18 SVE wells (1-8, 12, 13, 21, 24-29, and 35). As described in the previous Biannual Progress Report covering the period from August 1995 to February 1996, the wellfield was reconfigured three times prior to this reporting period to focus treatment to those soils that previously may have received little air flow.

The SVE system was reconfigured at the end of the previous reporting period (February 1996) to assure air flow was concentrated in the northern section of the treatment area. Flow was turned off in the southernmost end of the site except for wells 57 and 60, which are located in the southwestern corner of the treatment area. This new wellfield configuration had wells 9, 11, 14, 17, 18, 31, 33, 35, 57, and 60 dedicated to vacuum withdrawal, and wells 1, 10, 15, 32, 34, 52, and 53 dedicated to pressure injection. Wells 3, 4, 12, 13, 51, 59, 63, and 64 were designated as passive injection wells, and the remaining wells were closed off to the atmosphere. Since the contaminant levels in air samples did increase substantially from the previous sampling event, the system was scheduled at that time to be operated under this configuration until contaminant levels approached a relatively constant level for benzene, toluene, ethylbenzene, and xylenes (BTEX) and total volatile organic compounds (TVOCs). Therefore, the management strategy developed during the previous reporting period was continued into this reporting period.

The site was visited five times during the reporting period by MWR operations personnel. Site visits were performed on April 4, April 30, June 11, June 25, and

August 13 of 1996. While on site, MWR personnel serviced the air handling machinery, made adjustments to increase system effectiveness, collected off-gas samples to monitor the volatile organic compound yield of the system, and made miscellaneous repairs to the system.

During the site visit on April 4, 1996, the hour meter was replaced and an automatic restart circuit was installed. The circuit was installed to restart the system automatically following power supply failure. The condensate transfer pump located between the knock-out tank and the water storage tank was replaced. The newly-installed pump was then used to transfer condensate from the knock-out tank to the water storage tank. Air flow rates to and from the SVE wells were equalized and a full round of air samples were collected for analysis of BTEX and TVOCs.

The water storage tank was found to be approximately half full upon arrival to the site on April 30, 1996. Since water was to be pumped from the storage tank in cell 306, MWR requested Mr. Tom Keifer of Day & Zimmerman to make arrangements to have the water pumped from the storage tank at cell 46 and be properly disposed. The system was shut down while arrangements were made to pump the water. A full round of air samples were collected before leaving the site and analyzed for BTEX and TVOCs. Mr. Keifer restarted the system following pump out.

Upon arrival to the site on June 11, 1996, the SVE system was discovered to be down due to a full knock-out tank. Since the system is not equipped with controls to automatically pump water from the knock-out tank, the system had automatically shut down during normal operation when the tank became full. Therefore, the process water was manually pumped to the water storage tank. A 1-inch PVC valve was also repaired in the group of PVC pipes which acts as the injection manifold. Routine maintenance was performed and the system was restarted without producing substantial volumes of water. A full round of air samples were collected before leaving the site and analyzed for BTEX and TVOCs.

During the site visit on June 25, 1996, the piping and effluent stack on the discharge side of the vacuum blower was replaced since the heat generated by passage of air through the positive displacement blower had caused the piping to deform. During both the June 25 and August 13, 1996 site visits, routine

maintenance was performed and water from the knock-out tank was manually pumped to the water storage tank. A full round of air samples were also collected and analyzed for BTEX and TVOCs for both site visits.

A total of 56 air samples were collected during the reporting period. Samples were collected from each sample tap on the extraction manifold (plus at least one total system sample) in two-liter Tedlar[®] gas sampling bags. Each bag was purged three times with the off-gas stream to be sampled prior to actual sample collection. A total system sample was collected by sampling the combined flow of the extraction manifold into one sample bag. Collected gas samples were returned to the MWR Organics Laboratory for analysis by gas chromatography for the presence of BTEX and TVOCs. Data are reported in parts of contaminants per million parts of air (ppm_v).

ENHANCED VOLATILIZATION RESULTS

Figure 2 illustrates the off-gas concentrations in the composite samples since start-up of the system (February 23, 1993) through August 31, 1996. Off-gas concentrations in composite samples during the reporting period fluctuated during operation and were a maximum of 0.4 ppm for BTEX compounds and 3,760 ppm for TVOCs. Elevated levels of BTEX and TVOCs were experienced following the wellfield reconfiguration performed in February 1996, and concentrations generally decreased to the end of the reporting period.

Table 1 shows the off-gas concentrations for the samples collected during this reporting period. A majority of the off-gas samples obtained during this period did not contain concentrations of BTEX above the detection limit (0.5 ppm), but concentrations as high as 5.8 ppm BTEX were detected (from well 57 on June 11, 1996). Estimated TVOC concentrations have ranged from the detection limit (1.0 ppm) to 8,000 ppm in samples collected this reporting period.

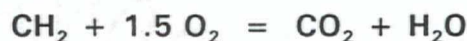
System off-gas yields derived from the off-gas data for the reporting period were calculated using the methods outlined in Attachment A. The yields were calculated using the data of the composite samples. The various flow rates required in the calculations are presented in Table 1. Table 2 lists the results of the yield calculations which represent the amount of contaminants captured per day of operation at the concentrations shown in Table 1 on the respective sampling dates. The yield data represent the removal rate through volatilization of the various target compounds during this reporting period by the SVE system. Table 3 presents the cumulative yield of the SVE system since start-up. Approximately 9,000 pounds of volatile petroleum hydrocarbons have been removed from the soils within the treatment cell since start-up, of which approximately 6,970 pounds have been removed during this reporting period. Since the total size of the treatment cell is approximately 18,500 cubic yards, or about 51.9 million pounds of soil, the 9,000 pound removal of contaminants represents a theoretical average reduction in soil contaminant concentration of 173 ppm. The contaminant concentration was reduced approximately 134 ppm during this 6 month reporting period. Of the 9,000 pounds,

approximately 11 pounds were BTEX compounds. Using the same methodology, the theoretical average reduction of BTEX compounds is approximately 0.22 ppm.

Figure 3 shows the cumulative yield curve since system start-up. The steep slope of the TVOC curve following the wellfield reconfiguration performed in February 1996 is an indication that the remediation system had quickly removed much of the contaminants from the new pathways. System operation should continue until the cumulative yield curve again declines to a relatively constant level.

BIODEGRADATION RESULTS

Carbon dioxide (CO₂) concentrations in the off-gas samples were measured to track biodegradation of petroleum hydrocarbon fuels by indigenous soil microorganisms. Normal concentrations of CO₂ in the atmosphere are approximately 300 ppm. Elevated CO₂ concentrations in the treatment cell indicate biological activity in the soil. The CO₂ concentrations will initially drop off during the early stages of SVE as the soil air is initially replaced with atmospheric air containing normal oxygen levels. As the soil microfauna is stimulated with oxygen in the injected air, the concentration of CO₂ will again rise above background levels. The microbes consume petroleum hydrocarbons in the soil converting the compounds to CO₂ and water following the general reaction below:



Removal of contaminants by biological degradation was calculated as outlined in **Attachment B**. The CO₂ concentrations measured during the reporting period are shown in **Table 1** for the corresponding sampling dates and withdrawal locations. **Table 2** presents the daily system yield due to biodegradation and represents yield per day during the individual sampling periods. **Table 3** lists the cumulative yield of contaminant compound removal by biodegradation. Approximately 21,800 pounds of hydrocarbons have been removed from the treatment cell through metabolism by the soil microorganisms since project start-up. Approximately 5,100 pounds have been removed during the period covered by this biannual progress report. The total reduction in contaminants in the treatment cell containing approximately 51.9 million pounds of soil amounts to a theoretical average reduction in concentration of approximately 420 ppm. The contaminant concentration was reduced approximately 98 ppm during this 6 month reporting period.

Figure 4 is the cumulative mass biodegradation (yield) curve since project start-up. The slope of the curve indicates an increased rate of contaminant removal by biodegradation since the wellfield was reconfigured in February 1996, which is an

indication that the remediation system is now more effectively degrading contamination from the area. The rate of removal remained approximately constant through the end of the reporting period except for the period in May 1996 when the increased groundwater elevations adversely affected biodegradation. Therefore, the system should continue operation until the cumulative yield curve again declines to a relatively constant level.

FUTURE ACTIVITIES

Future activities at the Test Cell #46 treatment cell for the next six months will include:

- Continue monthly site visits for maintenance of the SVE system.
- Continue monthly collection of operational off-gas samples.
- Continue analysis of data.
- Operate in the current configuration until the off-gas and biodegradation yield rates approach a relatively constant level.

FIGURES

AIR COOLER AND
GAS COMPRESSOR

S 62
D 56

S 55
D 64

S 63
D 54

S 53
D 52

S 61

S 51

58

59

50

S 57
D 60

ROADWAY

12 13

11

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34

35

PIPE
MANIFOLDS

VES-5

VES-6

VES-7

VES-8

BLDG. 437

HAVENS
COOLING
TOWER
439

PUMP
STATION

STOCKPILE

AG TANK
WITH
CONTAMINANT

N

EXPLANATION:

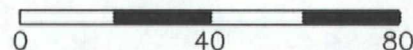
ETG SVE WELL

S SHALLOW WELL SET @6'

D DEEP WELL SET @12'

WELLS 26-35 WERE INSTALLED
BY O'BRIEN & GERE

Scale In Feet



AAAR
INCORPORATED

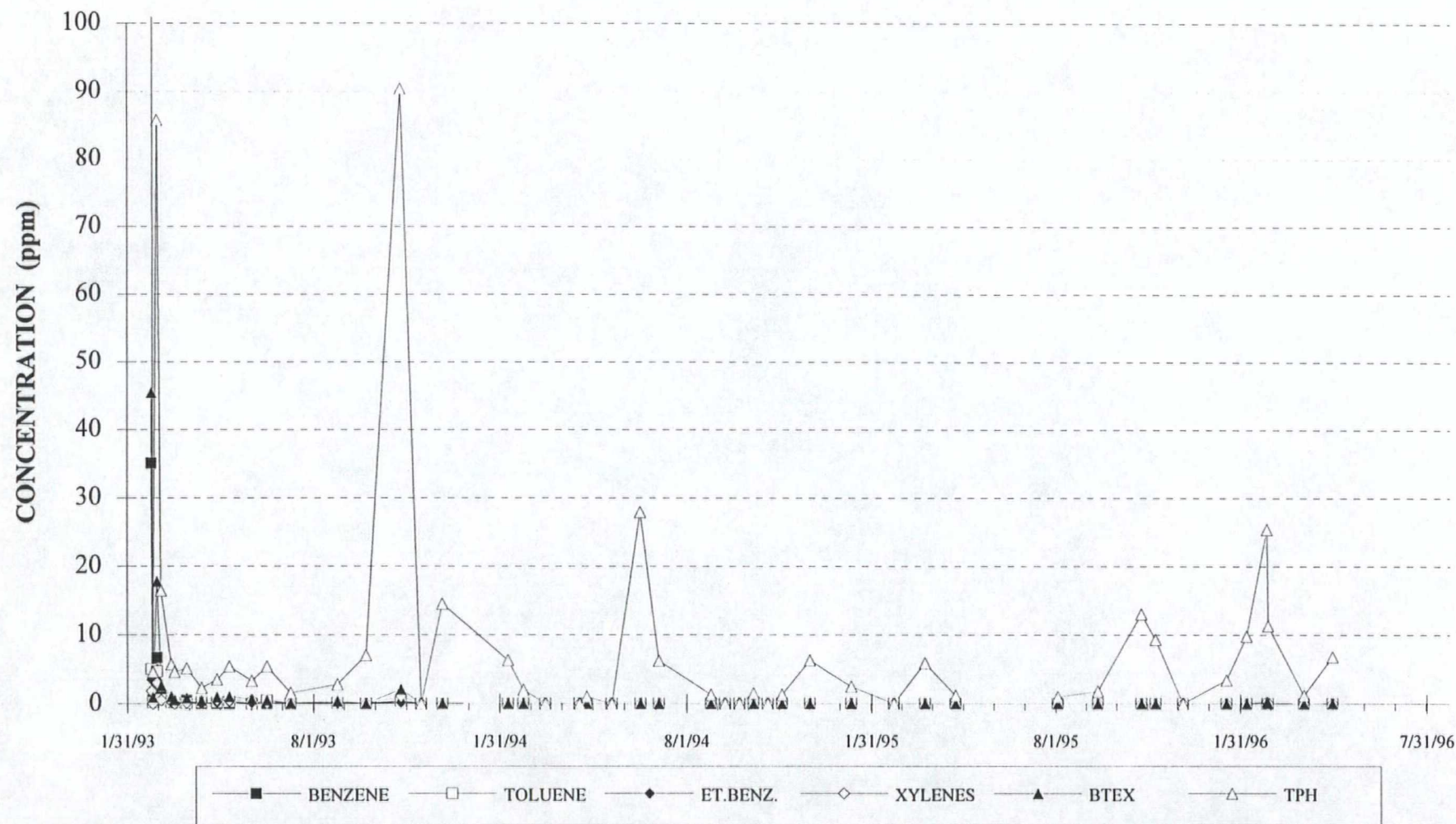
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GENERAL ELECTRIC EVANDALE, OHIO

CELL 46 SVE WELL LAYOUT

REV. 2	DRAWN BY M. Brocker	DATE 3/28/96
PROJECT MGR. M. Holland	DRAWING NO. 2002-46.DWG	FIGURE 1

Figure 2
OFF - GAS CONCENTRATION OF CONTAMINANTS
SOIL VAPOR EXTRACTION SYSTEM - COMPOSITE SAMPLE
G.E. BLDG. 306: CINCINNATI, OHIO



TPH detection limit = 1 ppm
 BTEX detection limit = .05 ppm

2/23/93 Composite sample has a THP concentration of 335.5 ppm

Figure 3
OFF - GAS CUMULATIVE YIELD OF VOCs
SOIL VAPOR EXTRACTION SYSTEM - COMPOSITE SAMPLE
G.E. Bldg. 306: CINCINNATI, OHIO

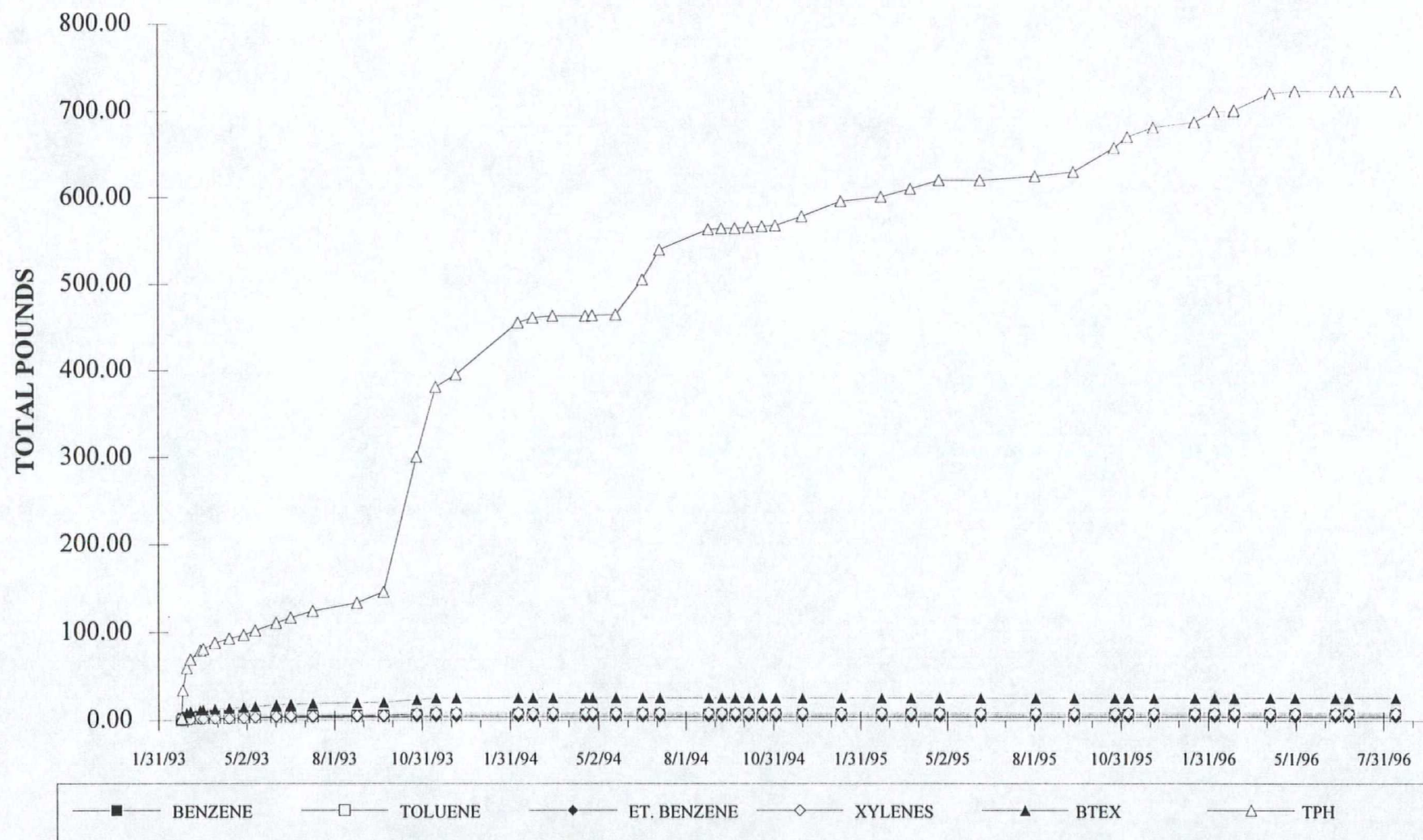
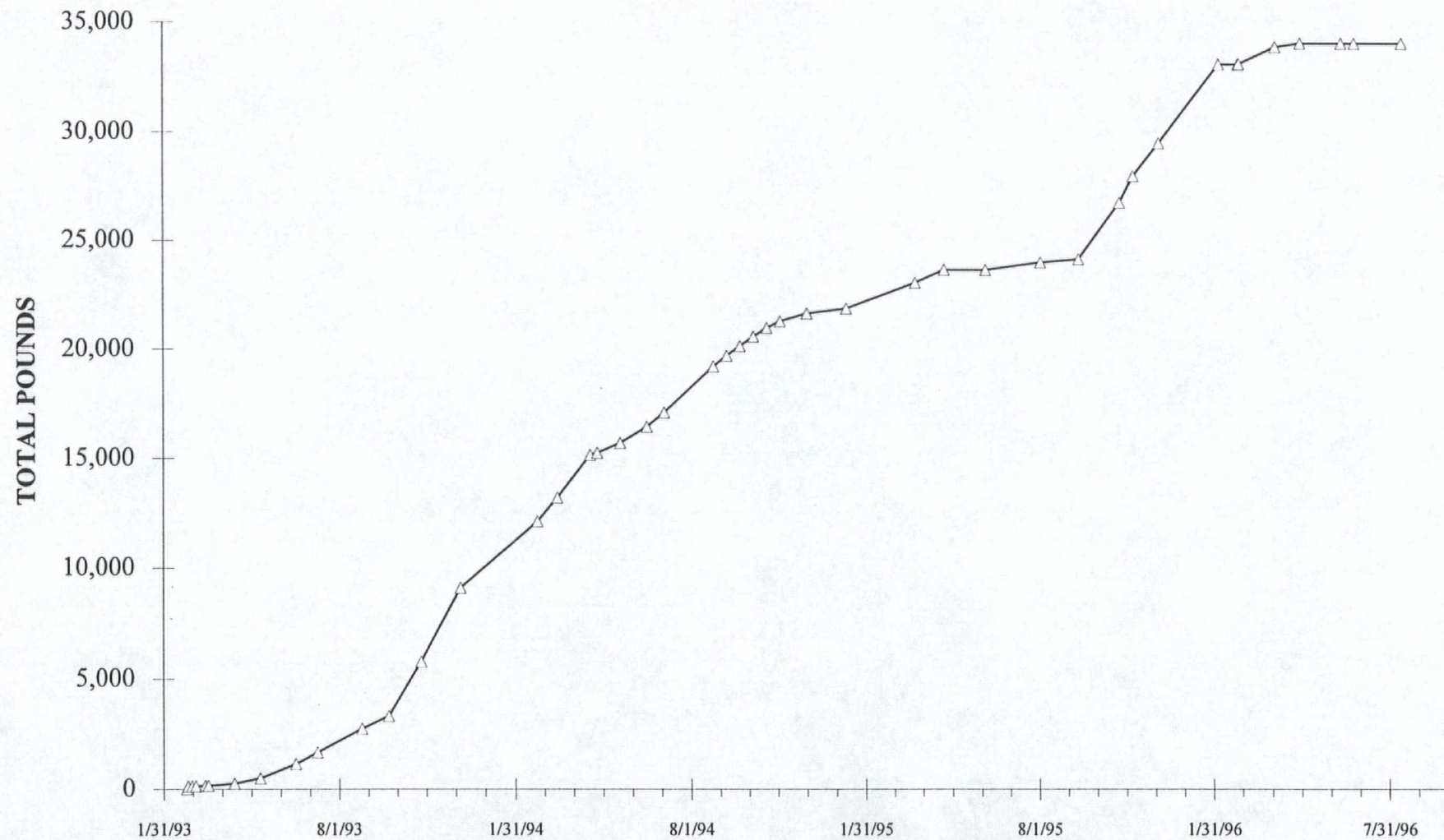


Figure 4
CUMULATIVE YIELD OF HYDROCARBON BIODEGRADATION
SOIL VAPOR EXTRACTION SYSTEM - COMPOSITE SAMPLE
G.E. Bldg. 306: CINCINNATI, OHIO



9/13/96

TABLES

Table 1: OFF - GAS CONCENTRATIONS

CLIENT: G. E. BUILDING # 306

CLIENT CODE: 2002

ANALYST: T. LONIEWSKI

PROJECT MANGER: M. HOLLAND

FIELD DATA					LAB DATA (ppm)				
SAMPLE DATE	SAMPLE #	WELL #	FLOW (CFM)	C02 (PPM)	BENZENE	TOLUENE	ET.BENZ.	XYLENES	TPH
4/4/96	COMP	COMP 306	280	2,800					1.20
4/4/96	Sample 1	21, 23, 25, 27, 29	100	5,000					<1.0
4/4/96	Sample 2	22, 24, 26, 28,	95	1,350					<1.0
4/4/96	Sample 3	42, 43, 45	85	1,650			0.05	0.06	<1.0
4/30/96	COMP	COMP 306	270	1,500				0.06	6.80
4/30/96	Sample 1	21, 23, 25, 27, 29	70	1,900					2.60
4/30/96	Sample 2	22, 24, 26, 28,	100	1,350				0.05	5.50
4/30/96	Sample 3	42, 43, 45	100	1,400		0.06		0.06	9.60
6/11/96	COMP	COMP 306	NS	NS	NS	NS	NS	NS	NS
6/25/96	COMP	COMP 306	NS	NS	NS	NS	NS	NS	NS
8/13/96	COMP	COMP 306	NS	NS	NS	NS	NS	NS	NS

* Blank cells represent BQL results.

NA = Not Analyzed

NS = Not Sampled

Table 2: REMOVAL RATES OF CONTAMINANTS

CLIENT: G. E. BUILDING # 306

CLIENT CODE: 2002

ANALYST: T. LONIEWSKI

PROJECT MANGER: M. HOLLAND

FIELD DATA		POUNDS OF CONTAMINANTS PER DAY					
SAMPLE DATE	WELL #	Hydrocarbon Biodegradation	BENZENE	TOLUENE	ET.BENZ.	XYLENES	TPH
4/4/96	COMP 306	36.59					0.13
4/4/96	21, 23, 25, 27, 29	24.57					
4/4/96	22, 24, 26, 28,	5.21					
4/4/96	42, 43, 45	6.00			0.00	0.00	
4/30/96	COMP 306	16.94				0.01	0.69
4/30/96	21, 23, 25, 27, 29	5.85					0.07
4/30/96	22, 24, 26, 28,	5.49				0.00	0.21
4/30/96	42, 43, 45	5.75		0.00		0.00	0.36
6/11/96	COMP 306	NS	NS	NS	NS	NS	NS
6/25/96	COMP 306	NS	NS	NS	NS	NS	NS
8/13/96	COMP 306	NS	NS	NS	NS	NS	NS

* Blank cells represent BQL results.

NA = Not Analyzed

NS = Not Sampled

Table 3
CUMULATIVE YIELD OF CONTAMINANTS
SOIL VAPOR EXTRACTION SYSTEM - COMPOSITE SAMPLE
G.E. BLDG. 306: CINCINNATI, OHIO

SAMPLE DATE	BENZENE	TOLUENE	ET. BENZENE	XYLENES	BTEX	TPH	HYDROCARBON BIODEGRADATION
2/23/93	0.21	0.04	0.03	0.02	0.29	2.62	11
2/25/93	2.81	0.48	0.40	0.20	3.90	34.48	137
3/1/93	4.39	1.75	1.46	1.11	8.72	59.88	139
3/5/93	4.95	2.21	1.85	1.46	10.47	69.46	141
3/15/93	5.43	2.59	2.17	1.88	12.07	79.81	154
3/18/93	5.48	2.65	2.23	1.93	12.28	81.25	163
3/30/93	5.84	2.80	2.49	2.02	13.16	88.07	NS
4/14/93	6.08	2.95	2.59	2.35	13.97	92.92	258
4/29/93	6.08	3.19	2.72	3.02	15.01	97.00	NS
5/11/93	6.08	3.46	2.99	3.63	16.16	102.00	505
6/2/93	6.08	3.73	3.40	4.67	17.89	110.56	NS
6/17/93	6.08	4.02	3.49	5.14	18.73	116.67	1,164
7/10/93	6.08	4.45	3.49	5.36	19.38	124.21	1,675
8/25/93	6.17	4.63	3.60	6.00	20.40	133.48	2,762
9/22/93	6.22	4.73	3.67	6.26	20.87	145.88	3,327
10/26/93	6.77	5.26	3.97	8.10	24.10	300.98	5,782
11/15/93	7.09	5.55	4.14	9.12	25.91	381.43	NS
12/6/93	7.13	5.55	4.14	9.12	25.95	395.69	9,101
2/8/94	7.27	5.55	4.14	9.12	26.09	456.09	NS
2/23/94	7.27	5.55	4.14	9.12	26.09	461.92	12,120
3/16/94	7.27	5.55	4.14	9.12	26.09	464.08	13,202
4/19/94	7.27	5.55	4.14	9.12	26.09	464.08	15,160

Table 3
CUMULATIVE YIELD OF CONTAMINANTS
SOIL VAPOR EXTRACTION SYSTEM - COMPOSITE SAMPLE
G.E. BLDG. 306: CINCINNATI, OHIO

SAMPLE DATE	BENZENE	TOLUENE	ET. BENZENE	XYLENES	BTEX	TPH	HYDROCARBON BIODEGRADATION
4/26/94	7.27	5.55	4.14	9.12	26.09	464.41	15,263
5/20/94	7.27	5.55	4.14	9.12	26.09	465.53	15,699
6/17/94	7.27	5.55	4.14	9.12	26.09	506.46	16,446
7/5/94	7.27	5.55	4.14	9.12	26.09	540.89	17,100
8/25/94	7.27	5.55	4.14	9.12	26.09	564.59	19,216
9/8/94	7.27	5.55	4.14	9.12	26.09	565.59	19,713
9/22/94	7.27	5.55	4.14	9.12	26.09	565.59	20,151
10/6/94	7.27	5.55	4.14	9.12	26.09	566.83	20,589
10/20/94	7.27	5.55	4.14	9.12	26.09	568.07	20,993
11/3/94	7.27	5.55	4.14	9.12	26.09	568.90	21,297
12/1/94	7.27	5.55	4.14	9.12	26.09	579.54	21,664
1/11/95	7.27	5.55	4.14	9.12	26.09	597.22	21,888
2/22/95	7.27	5.55	4.14	9.12	26.09	602.36	NS
3/25/95	7.27	5.55	4.14	9.12	26.09	611.63	23,078
4/24/95	7.27	5.55	4.14	9.12	26.09	621.51	23,675
6/6/95	7.27	5.55	4.14	9.12	26.09	621.51	23,676
8/3/95	7.27	5.55	4.14	9.12	26.09	626.64	24,033
9/12/95	7.27	5.55	4.14	9.12	26.09	631.48	24,180
10/25/95	7.27	5.55	4.14	9.12	26.09	659.50	26,768
11/8/95	7.27	5.55	4.14	9.12	26.09	672.26	28,006
12/5/95	7.27	5.55	4.14	9.12	26.09	683.32	29,521
1/17/96	7.27	5.55	4.14	9.12	26.09	689.47	NA

Table 3

CUMULATIVE YIELD OF CONTAMINANTS
SOIL VAPOR EXTRACTION SYSTEM - COMPOSITE SAMPLE
G.E. BLDG. 306: CINCINNATI, OHIO

SAMPLE DATE	BENZENE	TOLUENE	ET. BENZENE	XYLENES	BTEX	TPH	HYDROCARBON BIODEGRADATION
2/6/96	7.27	5.55	4.14	9.12	26.09	702.02	33,143
2/26/96	7.27	5.55	4.14	9.13	26.09	702.18	33,148
2/27/96	7.27	5.55	4.15	9.14	26.11	703.78	33,158
4/4/96	7.27	5.55	4.15	9.29	26.26	723.45	33,938
4/30/96	7.27	5.55	4.15	9.31	26.28	726.00	34,105
6/11/96	7.27	5.55	4.15	9.31	26.28	726.00	34,105
6/25/96	7.27	5.55	4.15	9.31	26.28	726.00	34,105
8/13/96	7.27	5.55	4.15	9.31	26.28	726.00	34,105

ATTACHMENT A

CONTAMINANT YIELD CALCULATION FOR SOIL VAPOR EXTRACTION SYSTEMS

The calculations described below were used to calculate contaminant yields from off-gas concentrations and flow rates. Concentration values were reported as ppm_v (μl/l) for each contaminant, and flows were reported as scfm (ft³/min). These concentration and flow data must be converted for use in Equation 1, to provide mass yield per unit time:

$$CONC \left(\frac{\text{mass}}{\text{volume}} \right) \times FLOW \left(\frac{\text{volume}}{\text{time}} \right) = YIELD \left(\frac{\text{mass}}{\text{time}} \right) \quad \text{EQN 1}$$

Final values will be expressed as pounds per day, which requires a series of units conversions. Since gas phase concentrations are reported in units of volume per volume, it is necessary to convert to a mass-per-volume expression for concentration. First, the ideal gas law is used to determine the number of moles, *n*, in a microliter of gas at 20° C:

$$P \cdot V = n \cdot R \cdot T \quad \text{EQN 2}$$

is rearranged to isolate moles:

$$n = \frac{P \cdot V}{R \cdot T} \quad \text{EQN 3}$$

where:

$$\begin{aligned} P &= 1 \text{ atm} \\ V &= 1 \text{ } \mu\text{l} = 1 \times 10^{-6} \text{ l} \\ R &= 0.08205 \text{ l-atm/mol-K} \\ T &= 20 \text{ } ^\circ\text{C} = 293 \text{ K} \end{aligned}$$

From EQN 3, above:

$$\frac{n}{\mu\text{l}} = \frac{1 \text{ atm} \cdot 1 \times 10^{-6} \frac{\text{l}}{\mu\text{l}}}{0.08205 \frac{\text{l-atm}}{\text{mol-K}} \cdot 293 \text{ K}} \quad \text{EQN 4}$$

Therefore, for any ideal gas at 20 °C and 1 atm,

$$\frac{n}{\mu\text{l}} = 4.16 \times 10^{-8} \frac{\text{mol}}{\mu\text{l}} \quad \text{EQN 5}$$

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Now the original concentration value which was expressed in units of $\mu\text{l}_{\text{contam}}$ per liter air (ppm_v) can be converted to moles per liter air:

$$C' \left(\frac{\text{mol}}{\text{l}_{\text{air}}} \right) = C \left(\frac{\mu\text{l}_{\text{contam}}}{\text{l}_{\text{air}}} \right) \times 4.16 \times 10^{-8} \frac{\text{mol}}{\mu\text{l}_{\text{contam}}} \quad \text{EQN 6}$$

The next step is to apply the formula weight, MW, for the compound of interest to convert from moles per μl to grams per l:

$$C'' \left(\frac{\text{g}}{\text{l}_{\text{air}}} \right) = C' \left(\frac{\text{mol}}{\text{l}_{\text{air}}} \right) \times MW \left(\frac{\text{g}}{\text{mol}} \right) \quad \text{EQN 7}$$

Substituting for C' from EQN 6 yields an expression which provides concentration values in units of mass per volume from the analytical result in ppm_v :

$$C'' \left(\frac{\text{g}}{\text{l}_{\text{air}}} \right) = C \left(\frac{\mu\text{l}_{\text{contam}}}{\text{l}_{\text{air}}} \right) \times 4.16 \times 10^{-8} \frac{\text{mol}}{\mu\text{l}_{\text{contam}}} \times MW \left(\frac{\text{g}}{\text{mol}} \right) \quad \text{EQN 8}$$

The remaining steps are simple units conversions. First, convert C'' from g/l_{air} to $\text{lb/ft}^3_{\text{air}}$:

$$C''' \left(\frac{\text{lb}}{\text{ft}^3} \right) = C'' \left(\frac{\text{g}}{\text{l}_{\text{air}}} \right) \times 0.0022 \frac{\text{lb}}{\text{g}} \times 28.3 \frac{\text{l}_{\text{air}}}{\text{ft}^3} \quad \text{EQN 9}$$

Next, convert flow, Q , from ft^3/min as measured in the field, to Q' needed for substitution into EQN 1, in units of ft^3/day :

$$Q' \left(\frac{\text{ft}^3}{\text{day}} \right) = Q \left(\frac{\text{ft}^3}{\text{min}} \right) \times 1440 \frac{\text{min}}{\text{day}} \quad \text{EQN 10}$$

Equation 1 can now be restated as follows:

$$\text{YIELD} \left(\frac{\text{lb}}{\text{day}} \right) = Q' \left(\frac{\text{ft}^3}{\text{day}} \right) \times C''' \left(\frac{\text{lb}}{\text{ft}^3} \right) \quad \text{EQN 11}$$

Finally, an equation can be stated which isolates the two measurements, Q (ft^3/min) and C ($\mu\text{l/l}$), and the formula weight of the compound of interest, MW (g/mol), and lumps the conversions from equations 8, 9 and 10 into a single number:

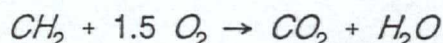
$$\text{YIELD} \left(\frac{\text{lb}}{\text{day}} \right) = Q \left(\frac{\text{ft}^3}{\text{min}} \right) \times C \left(\frac{\mu\text{l}_{\text{contam}}}{\text{l}_{\text{air}}} \right) \times MW \left(\frac{\text{g}}{\text{mol}} \right) \times 3.73 \times 10^{-6} \frac{\text{mol} \times \text{lb} \times \text{l}_{\text{air}} \times \text{min}}{\mu\text{l}_{\text{contam}} \times \text{g} \times \text{ft}^3 \times \text{day}} \quad \text{EQN 12}$$

ATTACHMENT B

BIODEGRADATION YIELD CALCULATION FOR SOIL VAPOR EXTRACTION SYSTEMS

The calculations described below were used to determine biodegradation yields from the soil vapor extraction system, based on differences between carbon dioxide (CO₂) concentrations in the injection and withdrawal air streams. CO₂ concentrations were measured in ppm_v, and air flows were recorded as scfm (ft³/min). These values can be used to calculate the metabolic conversion of petroleum hydrocarbons, given the following assumptions:

1. CO₂ enrichment of the SVE-induced air flow is entirely attributable to biodegradation of petroleum hydrocarbons. This assumption overlooks two potential sources of CO₂: biodegradation of native soil organics, and de-gassing of CO₂-rich groundwater. It also overlooks soil carbonate minerals, which are a potential CO₂ sink. In a site known to contain petroleum hydrocarbons, this error is expected to be small relative to CO₂ production rates.
2. CH₂ is representative of the basic petroleum hydrocarbon carbon-hydrogen ratio. The aerobic respiration of CH₂ is then summarized by the following stoichiometry:



For every CH₂ unit degraded by soil microbes, one CO₂ molecule is added to the soil atmosphere. Therefore, the CO₂ provides a one-to-one molar representation of the metabolic conversion of petroleum hydrocarbon.

The first step in the calculation of biodegradation yield is the conversion of field data for carbon dioxide concentrations from volumetric (ppm_v, or μlCO₂/l_{air}) to molar concentrations (mol CO₂/l_{air}). To do this, the ideal gas law is used to calculate the number of moles, n, in a μl of gas at 20° C:

$$P \cdot V = n \cdot R \cdot T \quad \text{EQN 1}$$

rearranged to isolate moles:

$$n_{\text{CO}_2} = \frac{P \cdot V_{\text{CO}_2}}{R \cdot T} \quad \text{EQN 2}$$

where:

$$\begin{aligned} P &= 1 \text{ atm} \\ V_{\text{CO}_2} &= 1 \text{ } \mu\text{l} = 1 \times 10^{-6} \text{ l} \\ R &= 0.08205 \text{ l} \cdot \text{atm} / \text{mol} \cdot \text{K} \\ T &= 20^\circ \text{ C} = 293 \text{ K} \end{aligned}$$

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From EQN 2, above,

$$\frac{n_{CO_2}}{\mu l_{CO_2}} = \frac{1 \text{ atm} \cdot 1 \times 10^{-6} \frac{l_{CO_2}}{\mu l_{CO_2}}}{0.08205 \frac{l \cdot atm}{mol \cdot K} \cdot 293 K} \quad \text{EQN 3}$$

Therefore, for CO_2 , as an ideal gas at $20^\circ C$ and 1 atm,

$$\frac{n_{CO_2}}{\mu l_{CO_2}} = 4.16 \times 10^{-8} \frac{mol_{CO_2}}{\mu l_{CO_2}} \quad \text{EQN 4}$$

Now the original concentration value which was expressed in units of μl_{CO_2} per liter air (ppm_v) can be converted to moles per liter air. The new concentration value is labelled as C' :

$$C' \left(\frac{mol_{CO_2}}{l_{air}} \right) = C \left(\frac{\mu l_{CO_2}}{l_{air}} \right) \times 4.16 \times 10^{-8} \frac{mol_{CO_2}}{\mu l_{CO_2}} \quad \text{EQN 5}$$

The next step is to apply the formula weight for the compound of interest, to convert from moles per μl to grams per l. Since the CO_2 is assumed to quantitatively represent petroleum hydrocarbon metabolized, and since CH_2 is assumed to be the representative hydrocarbon unit, the molecular weight of CH_2 (14.0 g/mol) will now be substituted for that of CO_2 :

$$C'' \left(\frac{g_{CH_2}}{l_{air}} \right) = C' \left(\frac{mol_{CO_2}}{l_{air}} \right) \times 1.0 \frac{mol_{CH_2}}{mol_{CO_2}} \times 14.0 \frac{g_{CH_2}}{mol_{CH_2}} \quad \text{EQN 6}$$

Substituting from EQN 5 for C' in EQN 6 yields an expression which provides concentration values in units of mass CH_2 per volume air from the CO_2 analytical result in ppm_v :

$$C'' \left(\frac{g_{CH_2}}{l_{air}} \right) = C \left(\frac{\mu l_{CO_2}}{l_{air}} \right) \times 4.16 \times 10^{-8} \frac{mol_{CO_2}}{\mu l_{CO_2}} \times 1.0 \frac{mol_{CH_2}}{mol_{CO_2}} \times 14.0 \frac{g_{CH_2}}{mol_{CH_2}} \quad \text{EQN 7}$$

The remaining steps are units conversions. First, convert C'' from g/l_{air} to lb/ft^3_{air} :

$$C''' \left(\frac{lb_{CH_2}}{ft^3_{air}} \right) = C'' \left(\frac{g_{CH_2}}{l_{air}} \right) \times 0.0022 \frac{lb_{CH_2}}{g_{CH_2}} \times 28.3 \frac{l_{air}}{ft^3_{air}} \quad \text{EQN 8}$$

Next, convert flow, Q , from ft^3/min as measured in the field, to Q' in units of ft^3/day needed for calculation of daily hydrocarbon biodegradation yield:

$$Q' \left(\frac{ft^3}{day} \right) = Q \left(\frac{ft^3}{min} \right) \times 1440 \frac{min}{day} \quad \text{EQN 9}$$

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An equation can now be stated which quantifies biodegradation yield as the product of air flow and off-gas metabolite concentrations:

$$BIO\ YIELD\ \left(\frac{lb_{CH_2}}{day}\right) = Q' \left(\frac{ft^3_{air}}{day}\right) \times C''' \left(\frac{lb_{CH_2}}{ft^3_{air}}\right) \quad EQN\ 10$$

Finally, EQN 10 can be restated, isolating the two field measurements, Q (ft³/min) and C (ppm, CO₂). The balance of the equation lumps the molecular weight for CH₂ and the units conversions from equations 7 through 9:

$$BIO\ \left(\frac{lb_{CH_2}}{day}\right) = Q \left(\frac{ft^3_{air}}{min}\right) \times C \left(\frac{\mu l_{CO_2}}{l_{air}}\right) \times 5.22 \times 10^{-5} \frac{min \times l_{air} \times mol_{CO_2} \times mol_{CH_2} \times g_{CH_2}}{day \times ft^3_{air} \times \mu l_{CO_2} \times mol_{CO_2} \times mol_{CH_2}} \quad EQN\ 11$$